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EFFECTS OF CONTROLLED SOIL MOISTURE ON GROWTH, COMPOSITION, YIELD, AND QUALITY OF MARYLAND TOBACCO[1]

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INTRODUCTION

Adequate soil and air moisture constitutes one of the cardinal requirements for the growth of leaf tobacco which must meet exacting commercial demands. Since the leaf of the tobacco plant (*Nicotiana tabacum* L.) is the final product, it must possess a more or less definite combination of shape, size, structure, elasticity, venation, color, and possibly other structural details not readily visible to the eye, as well as a rather characteristic chemical composition which determines aroma, taste, and unidentified characters indicative of quality. The fire-holding capacity of the cured leaf is strikingly modified by both the structural details and the chemical composition. These properties in turn are influenced and modified by soil moisture, which largely controls the growth of all parts of the plant, especially the leaf structure.

It is generally recognized by the tobacco trade that leaf grown during a dry season is very different from that grown during a wet one. The adaptability of the two products to manufacturing purposes differs widely. The leaf produced during a dry season is small, dark and dull in color, high in nicotine, and lacking in elasticity. It possesses more aroma associated with gums and resins, has a dense structure associated with a high weight per unit area, characteristically possesses low fire-holding capacity, and manifests a slow and inactive fermentation when bulked or packed. The cured leaf from tobacco produced during a season with adequate and well-distributed moisture, on the other hand, other conditions being equal, is thin, of an open structure or texture associated with a light weight per unit area, comparatively large, light and bright in color, elastic, low in nicotine, weak in aroma, and low in gums and resins and shows an active and rapid fermentation when bulked.

Although to a greater or less extent soil moisture appears to be the dominant factor, atmospheric humidity, shading associated with cloudiness, and air movements that increase the evaporating power of the air are all a part of the complex which controls plant growth and development. The organic matter and the mineral constituents that affect the physical condition of the soil and control the retention

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and release of moisture to the growing plant are highly important factors in the utilization of soil moisture by plants in the development of leaves.

In the 1941 Yearbook of the United States Department of Agriculture Garner (*5*)[2] discussed the effects of climate on the growth of tobacco. There are few publications dealing with the effects of supplemental water on the production of tobacco in humid areas. The work by Goff (*7*) was possibly the earliest account in this country of the effect of irrigation on the growth of tobacco. Anderson and his associates (*1*, *2*, *3*) reported the effects of irrigation on the yield and quality of cigar tobacco at the Tobacco and Vegetable Substation at Windsor, Conn.

The classic work of Hasselbring (*9*, *10*), although it does not deal directly with irrigation, has a bearing on the subject since shading affects plant and soil-moisture relations. This relation was further emphasized by the work of Stewart (*16*), who showed that average soil moisture, air temperature, and humidity were higher when tobacco was grown under a cloth shade than when grown under comparable conditions without shade. A partial explanation of some of these effects may be found in the work of G. W. Volk (*17*) and N. J. Volk (*18*), who studied the effects of the wetting and drying of a soil on potash fixation. McMurtrey (*13*) described the symptoms of nitrogen deficiency, which, according to Anderson and his coworkers (*1*, *2*, *3*), are often associated with irrigation effects. The review by Kramer (*12*) brought up to date the contributions on soil moisture in relation to plant growth.

MATERIALS AND METHODS

As previously stated, tobacco leaf grown during dry weather manifests certain characteristics that differ from those of leaf produced during wet weather. Since the two conditions do not occur simultaneously, a direct comparison of the leaf produced in the same season under the two conditions is not possible. It seemed desirable, therefore, to set up experimentally these two conditions insofar as possible in order to arrive at a more complete understanding of the effects of insufficient and of adequate moisture on growth and character of the leaf produced. Such effects were evaluated by systematic measurements, chemical analyses, and any other evident changes in the character of the leaf.

The unvaried cultural and handling procedures (*15*) in general were those used by successful growers of the Maryland type of tobacco. Crop yields and values were determined after stripping, grading, weighing, and sampling. Samples so obtained were submitted to experienced judges of Maryland tobacco, who assigned values. Calculations based upon weights and values thus obtained were the source of the results reported on yields and gross values per acre. Tests to determine the fire-holding capacity of cured leaves of the cigarette grades were made according to the usual laboratory procedures. Twenty-five leaves from as many plants were ignited by an electric lighter. These tests were carried out under controlled temperature and humidity.

[2] Italic numbers in parentheses refer to Literature Cited, p. 248.

The various artificial weather conditions were set up after the plants had become well established. There were three treatments in 1934, each on a separate plot, which was given the same number as its treatment. One area was held dry continuously by means of a tarpaulin rolled down just before a rain and supported by suitable scaffolding, as shown in figure 1. The second area was irrigated twice weekly, receiving one-fourth inch of water each time during weeks when no rain fell, and the third area in like manner received an equivalent of one-half inch of water. The water was added as a spray by means of overhead nozzles.

FIGURE 1.—Tobacco grown (*A*) without water during early growth and (*B*) with both rainfall and supplementary water equivalent to one-half inch twice a week when insufficient rain fell during early growth. Photographed August 10, 1936. Note scaffolding for support of canvas and movable irrigation pipe with nozzles.

In 1935 and thereafter five treatments were used on as many areas in two different series: A, lowland, and B, upland. In addition to the area kept dry continuously as in the previous year (No. 1), there was a second area irrigated by overhead nozzles to add one-half inch of water twice weekly if there was no rainfall during the week (treated like No. 3 in 1934). A third area was irrigated in the same manner early in the season and kept dry for the remainder of the season by means of a tarpaulin as on area 1. A fourth area was kept dry like area 1 during the early part of the season and irrigated like area 2 during the last part of the season. Tobacco grown on the fifth area (the control area) was produced under the prevailing rainfall. The plan was to roll the covers down just before a rain and to roll them up as soon thereafter as practicable. This procedure was followed in an effort to avoid shading. To give protection from showers during the night also, an attendant was on hand to apply covers when a shower threatened.

TABLE 1.—*Amounts of rainfall and irrigation water (inches) and dates of transplanting, replanting, irrigating, topping, and harvesting tobacco nd of applying and changing covers, Upper Marlboro, Md., 1934–40*

[C, Covers applied to withhold rainfall from plots 1A, 1B, 4A, and 4B; CR, covers changed from plot 4A to plot 3A and from plot 4B to plot 3B; W, water (equivalent to ½ inch) added to plots 2A, 2B, 3A, and 3B early in season and to plots 4A and 4B late in season; P, transplanting; RP, replanting; H, harvesting; T, topping. In the treatment or plot numbers, A indicates lowland series and B upland series. Zeros were not added to indicate that no rain fell on the dates when operations were carried on]

RAINFALL

Date	June							July							August							September [1]					4-month total						
	1934	1935	1936	1937 [2]	1938	1939	1940	1934	1935	1936	1937	1938	1939	1940	1934	1935	1936	1937	1938	1939	1940	1934	1935	1937	1939	1940	1934	1935	1936	1937	1938	1939	1940
1	0	0	0	0	0	0	0	0	0	0	0	0	0	0.37	0.01	0	0	0	0	0	0	0	0.01	0	W	1.63							
2	0	0	0	.07	0	0	0	0	0	.07	.08	.10	0	0	0	W	0	.02	.07	W	W	0	0	0	0	0							
3	0	.04	.17	.37	0	0	0	0	0	{C, .67}	C	0	0	1.45	W	0	0	W	{W, .33}	.14	0	.56	.13	H	0	0							
4	0	0	0	0	0	0	0	0	0	.12	0	0	.08	.46	0	0	0	0	.63	.08	0	0	0		2.65	0							
5	0	1.07	0	0	0	0	0	.57	0	0	2.50	0	.09	0	.25	0	.03	0	0	0	0	0	3.88		0	0							
6	0	0	0	.07	0	0	0	0	0	0	0	0	0	0	0	W	0	W	0	0	{W, .40}	0	{3.56, H}		0	H							
7	0	P	.01	.10	0	0	0	0	0	0	0	0	0	0	W	.80	.25	0	0	0	.12	3.78			0								
8	0	.80	0	0	0	0	.12	.02	1.70	0	0	C	C	0	.03	0	0	.65	0	W	0	H			0								
9	0	0	0	0	0	0	.21	0	{C, .48}	0	.05	.03	0	0	.03	0	0	.06	W	0	W				0								
10	0	0	0	1.10	0	0	0	W	.61	{.15, W}	0	0	0	C	W	0	0	0	.17	0	0				.85								
11	0	0	.64	RP	0	0	0	C	0	0	.67	0	W	0	0	0	.01	0	0	W	.19				0								
12	.21	.35	P	0	.29	0	0	0	0	.17	0	.06	0	1.45	.50	0	CR	{T, CR, 1.03}	{CR, W}	0	0				H								
13	0	0	0	0	.01	1.57	0	.07	.80	0	0	0	.03	.55	0	{W, .24}		.41	0	.03	W												
14	0	0	.13	1.17	0	0	0	0	0	W	.02	.10	{.02, W}	0	0	.01	W	0	0	.02	0												
15	0	0	0	.25	P	0	0	0	0	0	.48	W	0	0	.04	0	0	0	0	W	{.48, T}												
16	0	0	0	.13	0	0	0	W	0	0	.08	0	0	.10	.76	CR	.07	0	0	0	0												
17	0	0	0	3.14	.25	0	{P, .04}	0	0	W	0	1.48	0	0	0	0	0	W	.44	0	.03												
18	1.13	0	0	52	0	0	0	0	0	0	0	0	.21	0	0	0	W	0	0	{W, 2.74}	0												
19	P	.91	0	0	.31	.15	0	0	W	0	0	0	0	W	0	.06	0	0	0	0	.13												
20	0	0	0	0	.11	0	0	W	0	0	.80	.20	0	0	0	.06	0	W	0	.05	{W, CR}												

| | | |

The rows were spaced 34 inches apart, and the plants were spaced the same distance in the rows. Each area was occupied by 8 rows of 14 plants each. The border plants were removed at harvest time; that is, the yields and other data were taken on the 72 plants inside the border. Each area received a fertilizer containing 4 percent of nitrogen (N) derived one-fourth from tankage, three-eighths from ammonium sulfate, and three-eighths from nitrate of soda; 8 percent of phosphoric acid (P_2O_5) derived from superphosphate; and 12 percent of potash (K_2O) derived from sulfate of potash. This mixture was applied in the row at the rate of 750 pounds per acre.

The dates of transplanting, watering, applying covers, changing covers, topping, harvesting, and replanting, as well as the dates and amount of rainfall and the amount of irrigation, are shown in table 1. Watering, or irrigation, was accomplished by means of overhead nozzles to simulate natural rainfall. Occasionally there was rain immediately after irrigation; this wet the soil excessively and produced more or less leaching on the irrigated areas. At times it was difficult to irrigate during windy periods because the spray tended to blow, but blowing was controlled satisfactorily by avoiding windy periods and by tilting the spray nozzles in such a way as to direct the spray to the desired area. The covered areas were left unprotected at the sides to avoid setting up a humid atmosphere under the tarpaulin, but no serious difficulty was encountered from blowing rains. Recording instruments under the tarpaulin showed no significant differences in temperatures and humidity from those recorded on an adjacent uncovered control area. It should be recognized, however, that the treatment on the dry plot did not entirely simulate natural drought conditions, because the atmosphere and the soil may not have been dry simultaneously. Besides, there were some effects of shading for it was not always desirable to roll up the tarpaulin immediately after a shower because of the danger of its molding and decaying.

The plots were located on soils of the Collington series, but the plants were not grown on the same areas for the entire period, because of the development of nematodes (*Heterodera marioni* (Cornu) Goodey) and of fusarium wilt, caused by *Fusarium oxysporum* f. *nicotianae* (J. Johnson) Snyder and Hansen. The lowland series (A) was located on one area in 1934, another in 1935, and a third from 1936 to 1940; on all of these the soil was mapped as Collington loamy sand and was definitely sandy with little or no subsoil. Except in 1936 and 1937, the upland series (B) was located on a slightly heavier soil with a definite subsoil at about 16 to 22 inches; it was mapped as Collington fine sandy loam. In 1936 and 1937 the soil was a loamy sand like that on which series A was located. The plots were in four different locations—one in 1934, a second in 1935, a third in 1936 and 1937, and a fourth from 1938 to 1940. The water applied to plots in the lowlands series was obtained from a deep well, and that applied to the upland series was ground water from a surface spring.

The Maryland Broadleaf variety was planted from 1934 to 1938 and the Maryland Medium Broadleaf in 1939 and 1940.

Some preliminary studies were made during 1934 and 1935 to determine the effect of irrigation on the percentage of moisture in the soil on a moist-weight basis (table 2). The soil samples were taken to a depth of 6 inches and represented 12 borings per plot. Soil

TABLE 2.—*Soil-moisture content based on moist weight before and after watering irrigation plots, Upper Marlboro, Md., 1934–35*

[Samples represent 12 borings per plot to a depth of 6 inches]

Date and treatment No.	Lowland (series A)		Upland (series B)	
	Before watering	After watering	Before watering	After watering
1934	*Percent*	*Percent*	*Percent*	*Percent*
June 27:				
1	4.37	.....	6.76	.....
2	4.57	.....	7.73	.....
3	6.47	.....	9.92	.....
July 5:				
1	4.39	.....	6.75	.....
2	4.76	.....	7.83	.....
3	5.92	.....	8.91	.....
July 10 and 11:				
1	4.37	6.39	6.23	6.13
2	4.75	6.34	6.92	9.11
3	6.23	6.38	8.61	13.38
July 16 and 17:				
1	4.21	4.37	5.40	5.71
2	4.67	6.12	7.00	9.35
3	7.06	7.89	9.48	12.13
July 24 and 25:				
1	3.46	4.06	5.19	5.49
2	4.30	5.48	5.98	7.46
3	5.91	8.27	8.81	11.57
July 31 and Aug. 1:				
1	3.73	3.47	5.90	5.21
2	7.21	6.05	10.39	8.45
3	8.79	7.51	13.32	11.94
Aug. 7 and 8:				
1	2.94	2.58	4.49	4.31
2	5.09	6.77	6.80	8.16
3	7.23	8.67	10.81	13.19
Aug. 14 and 15:				
1	2.88	2.57	3.71	3.76
2	7.29	6.28	9.65	7.80
3	9.27	9.21	13.93	12.93
Aug. 21 and 22:				
1	2.57	2.28	2.99	2.47
2	4.59	6.31	6.31	7.59
3	5.97	7.99	11.51	13.44
Aug. 28 and 29:				
1	1.85	1.90	2.75	2.81
2	6.74	5.30	8.32	7.67
3	7.70	6.95	13.18	12.92
Sept. 4 and 5:				
1	1.40	1.25	2.10	2.20
2	7.67	5.78	9.78	8.20
3	8.42	7.11	13.41	11.83
1935				
June 26:				
1	5.46	.....	8.30	.....
2	5.23	.....	8.13	.....
3	4.63	.....	8.21	.....
4	5.43	.....	7.83	.....
5	5.71	.....	7.80	.....

Date and treatment No.	Lowland (series A)		Upland (series B)	
	Before watering	After watering	Before watering	After watering
1935	*Percent*	*Percent*	*Percent*	*Percent*
July 3:				
1	4.71	.....	6.69	.....
2	4.62	.....	6.21	.....
3	3.86	.....	6.27	.....
4	4.24	.....	6.37	.....
5	4.84	.....	6.50	.....
July 9:				
1	4.72	.....	6.38	.....
2	7.96	.....	11.07	.....
3	7.71	.....	10.99	.....
4	4.05	.....	6.03	.....
5	8.26	.....	10.88	.....
July 16:				
1	4.43	.....	5.77	.....
2	5.62	.....	10.17	.....
3	5.32	.....	9.88	.....
4	4.61	.....	6.14	.....
5	5.95	.....	9.57	.....
July 23 and 24:				
1	3.45	3.64	4.42	4.20
2	4.94	8.57	7.66	10.61
3	3.90	8.11	8.29	11.13
4	2.65	2.48	5.01	4.82
5	4.16	6.91	6.61	8.79
July 30 and 31:				
1	2.44	2.42	3.25	3.08
2	4.02	8.34	7.91	9.96
3	2.83	7.38	7.40	10.36
4	1.67	1.55	3.86	3.77
5	2.59	2.64	4.90	4.44
Aug. 6 and 8:				
1	1.92	2.04	2.54	2.40
2	4.45	8.71	6.02	11.04
3	3.42	8.07	6.78	11.25
4	1.11	1.10	2.76	2.68
5	1.67	7.46	2.43	8.67
Aug. 13 and 14:				
1	1.68	1.82	1.98	1.95
2	4.43	8.14	7.11	10.05
3	3.51	7.63	7.33	10.54
4	.98	1.07	2.09	2.23
5	2.65	3.36	4.03	4.45
Aug. 23 and 24:				
1	1.52	1.38	2.02	1.84
2	8.54	8.71	10.64	11.41
3	3.26	3.01	6.09	5.79
4	7.69	8.55	8.53	9.30
5	7.90	5.98	8.29	6.71

moisture was determined by drying to constant weight in an electric oven held at 105 ° C.

The official methods (*4*) were employed in obtaining the analytical results reported for starch, reducing sugars, sucrose, ash, phosphoric acid (P_2O_5), lime (CaO), magnesia (MgO), and sulfur (S). Corrections for sand and other siliceous soil material as applied in official methods (*4*) were used as a basis for calculating the results (see tables 9–13). Moisture in the leaf was determined by drying it at 100° C. for 4 hours. Nitrogen (N) was determined by the official Gunning method modified to include nitrate as given for fertilizers, with the substitution

of 0.7 gm. of mercuric oxide for copper oxide. Potash (K_2O) was determined by solution of sample by the wet digestion method of West (*19*) and the modified chloroplatinate method of Hicks (*11*). The weights of leaf material shown in tables 4 to 8 include the midrib and were not corrected for sand and other siliceous material, whereas the data shown in tables 9 and 10 were corrected for siliceous soil material and do not include the midrib. Nicotine was determined by a modification of the Keller method (*6*) made in the Division of Tobacco and Plant Nutrition.

EXPERIMENTAL RESULTS

PHYSICAL MEASUREMENTS

The water content of the surface soil was definitely modified by the methods used to control the water supply (table 2). It is inconceivable that the plants growing on the area to which no water was added and having a moisture content as low as 1 or 2 percent could have developed at all unless they were drawing on subsoil reserves. Soil-moisture content at greater depths shown in table 3 for 1937 indicated that this was taking place. The plants growing under these conditions as a rule exhibited severe wilting during the day and more or less wilting (fig. 1) at all times, but they did not show any considerable loss of the lower leaves from drying (see tables 4 and 5). At times during dry periods the water content of the soil of the control plot was as low as that of the soil of area 1, which received no rainfall and no irrigation. This condition was usually of short duration, however, since as a rule rain fell in time to correct this critical situation. When the water was withheld from area 3 late in the season, usually about 2 to 3 weeks before harvest, the soil moisture was rapidly reduced to a low level by the growing plants (tables 2 and 3).

TABLE 3.—*Soil-moisture content based on moist weight at 2 depths in irrigation plots, Upper Marlboro, Md., 1937*

[Samples represent 12 borings per plot]

Date and treatment No.	Lowland (series A)		Upland (series B)		Date and treatment No.	Lowland (series A)		Upland (series B)	
	0–12 inches	12–24 inches	0–12 inches	12–24 inches		0–12 inches	12–24 inches	0–12 inches	12–24 inches
	Per-cent	*Per-cent*	*Per-cent*	*Per-cent*		*Per-cent*	*Per-cent*	*Per-cent*	*Per-cent*
July 28:					August 11—Con.				
1	6.75	13.73	3.33	5.31	4	3.50	9.61	3.43	4.81
2	8.60	11.42	7.77	7.85	5	5.38	8.16	4.09	3.86
3	7.82	11.99	7.97	7.80	August 18:				
4	5.62	12.05	3.96	5.54	1	3.16	10.00	2.35	3.76
5	6.36	9.76	3.81	5.54	2	8.47	11.45	7.49	3.92
August 4:					3	5.61	9.54	4.33	7.15
1	5.02	12.48	3.04	4.82	4	7.32	10.64	6.66	4.68
2	8.35	10.81	7.38	6.94	5	5.32	7.80	4.49	5.42
3	8.55	11.62	7.42	7.56	September 1:				
4	4.98	9.67	3.42	5.20	1	4.13	9.12	2.46	3.61
5	4.45	8.50	3.14	4.69	2	8.91	12.89	7.02	8.21
August 11:					3	6.55	8.29	3.86	4.92
1	3.69	11.40	2.61	4.05	4	8.10	15.22	7.08	8.78
2	7.95	10.55	6.22	7.10	5	8.28	12.27	6.28	7.32
3	7.53	10.67	6.51	6.67					

The actual growth rate of the plant can most satisfactorily be expressed in terms of measurements made at intervals of the height of the plant and of the width and length of the leaves and of counts of the leaves. Dry-weight data to determine at intervals the increase in dry matter necessitate the harvesting and destruction of part of the experimental plantings and so generally are not feasible.

The leaf area developed by the plants was determined at 14-day intervals. The method used was based upon the formula by Goff (*7, p. 374*):

> The area of a leaf was computed by multiplying its length by one-half its width, and increasing the product by one-third, it having been ascertained by trial that this is nearly exact. The average length and the average width of a leaf was ascertained by taking measurements of 800 whole leaves.

More recently a mathematical method for determining the area of tobacco leaves was reported by Gubenko (*8*). The methods discussed in his paper appear to agree very closely with Goff's formula $L \times 1/2\ W$ increased by 1/3, in which L represents the length and W the width of the leaf. This formula can also be expressed as $2/3\ L \times W$. While Goff used the average length and width in his calculations, possibly for leaves of nearly the same size, this procedure would not be accurate if the leaves varied greatly in size, as from the bottom to the top of the plant. The area of each leaf would then have to be determined as a unit and the total for the plant arrived at by summation; this procedure was followed to obtain the results reported in tables 4, 5, 7, and 8.

The areas of leaves by groups with reference to position on the stalk and the total leaf area per plant are shown for the two varieties of Maryland tobacco in tables 4 and 5. At the time of the first measurements, approximately 30 days after transplanting, comparatively little variation in size of plants on the several plots was shown by the data on total leaf area, height of plant, number of leaves, and length of internodes. The two varieties, Maryland Broadleaf and Maryland Medium Broadleaf, had leaf areas approximating 3 or 4 square feet per plant at the time of the first measurement, and the two varieties and the five treatments were in reasonably close agreement. The subsequent measurements, however, showed decided differences for both varieties as a result of the various water treatments. The use of supplemental water in treatment 2 almost doubled the leaf area per plant as compared with treatment 1 with neither rainfall nor irrigation. The Maryland Broadleaf consistently produced plants with a greater leaf area than the Maryland Medium Broadleaf. However, there was no decided difference in the area per plant in the dry and control treatments. There was a loss of area by the lower leaves as a result of drying, or firing. The leaf area finally attained in square feet per plant roughly paralleled the number of leaves from plants grown on areas which were supplied with water treatment 2 (throughout the period) or treatment 3 (only during early growth).

The plots to which additional water was supplied produced taller plants with longer internodes and more total leaves than those on the area from which water was withheld. The plants of the Maryland Broadleaf variety grown on areas kept dry during early growth had more green leaves than those on irrigated areas (table 4). The Maryland Broadleaf variety developed more leaves than the Maryland Medium Broadleaf and reached its maximum leaf area 2 weeks

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TABLE 4.—*Average area of green leaves, height of plant, length of internodes, and number of leaves per plant of Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1936–38*

[Counts and measurements made at 14-day intervals on 24 plants comprising 2 rows, or one-third, of each plot in series B]

Measurement and treatment No.	Water treatment				Leaf area per plant								Height of plant	Average internode length	Leaves per plant		
	Precipitation		Irrigation		Groups of 5 leaves [1]							Total			Green	Dry	Total
	Early	Late	Early	Late	I	II	III	IV	V	VI	VII						
					Square feet	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square foot*	*Square feet*	*Inches*	*Inches*	*Number*	*Number*	*Number*
First:																	
1	Without	Without	Without	Without	1.18	1.59	0.29	0.02				2.99	5.94	0.53	11.21		11.21
2	With	With	With	With	1.28	1.57	.22	.01				3.08	5.95	.53	11.15		11.15
3	do	Without	do	Without	1.20	1.38	.18	.01				2.77	5.29	.50	10.54		10.54
4	Without	With	Without	With	1.27	1.17	.11					2.55	5.17	.51	10.05		10.05
5	With	do	do	Without	1.25	1.43	.30	.03				3.01	5.67	.52	10.91		10.91
Second:																	
1	Without	Without	do	do	1.22	3.49	3.10	.83	0.06			8.70	15.87	.92	16.30	1.03	17.33
2	With	With	With	With	1.41	4.94	5.57	2.27	.27	0.01		14.47	18.51	.90	19.19	1.28	20.47
3	do	Without	do	Without	1.41	4.72	4.92	1.71	.18			12.94	17.68	.92	18.22	.95	19.17
4	Without	With	Without	With	1.42	3.70	3.01	.57	.02			8.72	15.57	.93	16.30	.47	16.77
5	With	do	do	Without	1.32	4.38	4.60	1.84	.34	.01		12.49	17.38	.92	17.49	1.37	18.86
Third:																	
1	Without	Without	do	do	.88	3.69	4.61	2.70	.93	.20		13.01	28.81	1.19	21.77	2.48	24.25
2	With	With	With	With	.61	5.14	8.04	7.12	4.05	1.44	0.14	26.54	45.34	1.51	26.22	3.85	30.07
3	do	Without	do	Without	.64	5.14	7.95	6.58	3.34	1.22	.13	25.00	43.24	1.41	26.98	3.71	30.69
4	Without	With	Without	With	1.12	4.04	4.99	3.00	1.00	.16		14.31	29.03	1.18	22.61	2.02	24.63
5	With	do	do	Without	.57	4.37	6.57	5.28	2.81	1.17	.17	20.94	39.13	1.42	23.72	3.87	27.59
Fourth:																	
1	Without	Without	do	do	.18	2.73	4.71	3.64	2.03	.20		13.49	30.93	1.22	20.31	5.06	25.37
2	With	With	With	With		2.27	7.04	8.14	6.11	1.60	.07	25.23	36.61	1.37	18.01	8.71	26.72
3	do	Without	do	Without	.03	2.37	7.29	7.87	5.83	1.17	.06	24.62	36.76	1.38	18.44	8.23	26.67
4	Without	With	Without	With	.54	3.98	5.95	5.65	4.26	.60	.02	21.00	33.72	1.29	22.13	4.02	26.15
5	With	do	do	Without	.01	2.30	5.75	6.56	4.54	.75	.04	19.95	32.92	1.26	18.07	8.15	26.22

[1] Bottom (I) and top (VII) groups did not always contain 5 leaves.

TABLE 5.—*Average area of green leaves, height of plant, length of internodes, and number of leaves per plant of Maryland Medium Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1939–40*

[Counts and measurements made at 14-day intervals on 24 plants comprising 2 rows, or one-third, of each plot in series B]

Measurement and treatment No.	Water treatment				Leaf area per plant						Height of plant	Average internode length	Leaves per plant		
	Precipitation		Irrigation		Groups of 5 leaves [1]				Total	Harvested			Green	Dry	Total
	Early	Late	Early	Late	Bottom (lost)	Lower	Middle	Top							
					Square feet	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Square feet*	*Inches*	*Inches*	*Number*	*Number*	*Number*
First:															
1	Without	Without	Without	Without	1.86	1.76	0.13		3.75	1.89	5.67	0.50	11.27	0.17	11.44
2	With	With	With	With	3.54	.42	.02		3.98	.44	6.15	.53	11.37	.33	11.70
3	do	Without	do	Without	2.83	.88	.07		3.78	.95	5.53	.48	11.34	.21	11.55
4	Without	With	Without	With	1.97	1.32	.16		3.45	1.48	5.70	.50	10.99	.38	11.37
5	With	do	do	Without	3.27	.64	.04		3.95	.68	5.28	.46	11.40	.04	11.44
Second:															
1	Without	Without	do	do	1.93	4.57	2.47	0.26	9.23	7.30	13.13	.70	17.31	1.42	18.73
2	With	With	With	With	6.17	4.24	1.88	.30	12.59	6.42	14.99	.74	18.73	1.46	20.19
3	do	Without	do	Without	4.54	4.81	2.49	.49	12.33	7.79	14.25	.71	18.55	1.50	20.05
4	Without	With	Without	With	2.19	4.00	2.32	.36	8.87	6.68	12.64	.67	17.21	1.67	18.88
5	With	do	do	Without	4.37	4.28	1.90	.33	10.88	6.51	13.83	.72	17.84	1.40	19.24
Third:															
1	Without	Without	do	do	.95	4.33	3.06	.79	9.13	8.18	28.37	1.34	17.30	3.90	21.20
2	With	With	With	With	5.51	5.44	4.57	2.10	17.62	12.11	39.89	1.60	21.03	3.87	24.90
3	do	Without	do	Without	4.04	6.09	5.14	2.42	17.69	13.65	36.90	1.46	21.49	3.80	25.29
4	Without	With	Without	With	1.24	4.10	3.57	1.07	9.98	8.74	26.95	1.18	18.56	4.34	22.90
5	With	do	do	Without	3.40	5.18	3.55	1.22	13.35	9.95	33.65	1.43	19.54	4.02	23.56
Fourth:															
1	Without	Without	do	do	.26	4.11	4.46	2.96	11.79	11.53	20.11	.87	17.00	5.99	22.99
2	With	With	With	With	2.47	6.30	6.60	6.00	21.37	18.90	22.43	.92	17.22	7.26	24.48
3	do	Without	do	Without	2.14	6.34	7.13	6.10	21.71	19.57	23.06	.95	17.70	6.52	24.22
4	Without	With	Without	With	.42	4.11	4.69	4.86	14.08	13.66	19.41	.88	15.91	6.23	22.14
5	With	do	do	Without	1.43	5.79	6.40	5.38	19.00	17.57	20.51	.85	17.20	6.79	23.99

[1] Bottom and top groups did not always contain 5 leaves.

earlier, indicating more rapid growth (fig. 2). The Maryland Medium Broadleaf was apparently more seriously affected by the early dry period (treatment 4), since it did not recover as quickly or produce as much leaf area as the Maryland Broadleaf when irrigation was resumed late in the season (fig. 3). The total leaf number, internode

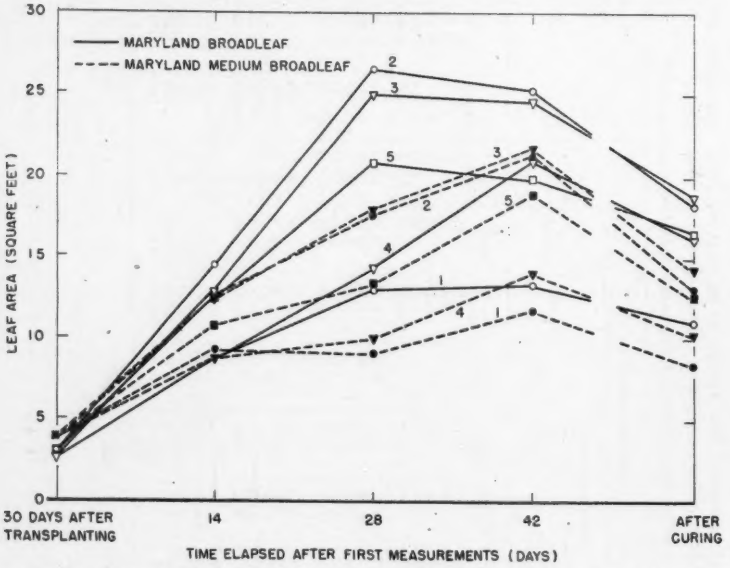

FIGURE 2.—Effect of irrigation on average leaf area per plant of the Maryland Broadleaf variety (1936–38) and the Maryland Medium Broadleaf (1939–40), when measured at 14-day intervals during the growing period and after curing. Data for cured leaf of the Maryland Medium Broadleaf are for 1939 only. Treatment 1, without rainfall or supplemental water during entire period of growth; treatment 2, with rainfall and supplemental water throughout period of growth; treatment 3, with rainfall and supplemental water during early period of growth, but without rainfall or supplemental water during late period of growth; treatment 4, without rainfall or supplemental water during early period of growth, but with rainfall and supplemental water during late period of growth; treatment 5, with rainfall, but without supplemental water during entire period of growth.

length, and height of plant showed much the same relation. The loss of the lower leaves was much more pronounced with both varieties on the plots furnished abundant moisture (rainfall and supplemental water).

A comparison of the leaves produced on dry soil and those produced on soil to which water was applied showed that the shape of the leaves was not greatly modified by the application of water. The ratio of length to width was practically constant except in the top leaves of Maryland Medium Broadleaf (table 6). The top leaves apparently increased in width where water was supplied. At the time of the fourth measurement the ratio of length to width was 2.41 with rainfall and supplemental water and 2.65 without either. The top leaves

were definitely longer in relation to width than the lower leaves. This relation changes gradually from the lower leaves, which were broad, to the middle leaves, which were narrow; the top leaves were the narrowest of the three groups. Although the addition of water did not greatly modify the shape of the leaf, it did cause a decided increase in size, as shown by measurements of length and width.

The measurements of the areas per plant of cured leaves, which possibly are not so accurate as those of the green-leaf areas, since it is difficult to smooth out cured leaves and obtain a true measure, showed decided differences as a result of the treatments (tables 7 and 8). The measurements were made and the data on moisture absorption were taken in a room where moisture and temperature

FIGURE 3.—Tobacco grown (*A*) without water during early growth, but with subsequent rainfall and supplemental water for 16 days and (*B*) with supplemental water and rainfall during early growth, but both subsequently withheld for 16 days. Photographed August 26, 1936. (Compare with fig. 1.)

were under control; they are, therefore, believed to be comparatively accurate. The moist and oven-dry weights of the cured leaves showed decided differences as a result of moisture supplied to the growing plants. The leaf of both varieties produced where water was withheld had the highest weight per square foot, but the Maryland Medium Broadleaf (table 8) had a higher weight per unit area than the Maryland Broadleaf (table 7). The 1940 crop was not included in the tabulation for cured leaf, as the control room was not available for handling the crop. As a rule the percentage of moisture absorbed by the cured leaf was highest where moisture was supplied in the field. Leaf grown on soil from which water was withheld early in the season was similar in moisture absorption and weight per square foot to that grown where water was withheld throughout the season (tables 7 and 8). Generally speaking, the leaf having the highest moisture-absorbing capacity and the lowest weight per square foot was produced on the plot from which water was withheld late in the season, that is, for 2 to 3 weeks before harvest (tables 7 and 8). The leaf produced on the control plot varied widely, depending upon the prevailing seasonal conditions.

TABLE 6.—*Average length and width of green leaves per plant of Maryland Medium Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1939–40*

[Measurements made at 14-day intervals during growing season; usually 5 or 6 leaves per group of lower, middle, and top leaves per plant (average of 24 plants)]

Measurement and treatment No.	Water treatment				Lower leaves			Middle leaves			Top leaves		
	Precipitation		Irrigation		Length	Width	Ratio (length/width)	Length	Width	Ratio (length/width)	Length	Width	Ratio (length/width)
	Early	Late	Early	Late									
First:					*Inches*	*Inches*		*Inches*	*Inches*		*Inches*	*Inches*	
1	Without	Without	Without	Without	10.40	5.57	1.87	3.10	1.31	2.37			
2	With	With	With	With	7.28	3.34	2.18	2.28	.81	2.81			
3	do	Without	do	Without	8.16	4.10	1.99	3.36	1.38	2.43			
4	Without	With	Without	With	9.72	5.00	1.94	5.81	2.34	2.48			
5	With	do	do	Without	7.69	3.70	2.08	3.19	1.23	2.59			
Second:													
1	Without	Without	do	do	17.90	9.86	1.82	13.46	6.22	2.16	7.37	2.60	2.83
2	With	With	With	With	18.84	10.06	1.87	13.27	5.64	2.35	8.35	2.88	2.90
3	do	Without	do	Without	18.74	10.38	1.81	13.57	6.13	2.21	8.32	2.90	2.87
4	Without	With	Without	With	17.58	9.42	1.87	13.81	6.43	2.15	7.86	2.83	2.78
5	With	do	do	Without	18.18	9.88	1.84	12.94	5.78	2.24	8.67	2.96	2.93
Third:													
1	Without	Without	do	do	18.18	9.66	1.88	15.50	6.76	2.29	10.44	3.45	3.03
2	With	With	With	With	22.45	11.28	1.99	21.34	9.15	2.33	15.85	5.60	2.83
3	do	Without	do	Without	22.47	11.75	1.91	21.60	9.68	2.23	16.06	5.81	2.76
4	Without	With	Without	With	18.34	9.70	1.89	17.32	8.12	2.13	12.58	4.99	2.52
5	With	do	do	Without	20.96	10.63	1.97	18.03	7.61	2.37	12.53	4.33	2.89
Fourth:													
1	Without	Without	do	do	18.45	10.31	1.79	18.48	8.69	2.13	15.08	5.70	2.65
2	With	With	With	With	23.21	12.67	1.83	24.56	11.69	2.10	23.53	9.77	2.41
3	do	Without	do	Without	22.70	12.35	1.84	25.04	11.73	2.13	23.97	9.64	2.49
4	Without	With	Without	With	18.91	10.27	1.84	19.99	9.53	2.10	18.14	7.48	2.43
5	With	do	do	Without	21.42	11.93	1.80	23.37	11.26	2.08	21.90	8.98	2.44

The values shown in tables 4 and 7 are averages for 3 years and represent data for series B only. The values for individual years did not show a wide departure from the averages, and the relative response to the treatments was much the same each year. The values in table 5 are averages from series B for 2 years, and the values for individual years showed no apparent significant departures from the averages.

The stalk weights showed a greater difference between treatments than leaf weights; the stalks tended to be relatively smaller on the dry plot than on the irrigated ones, as shown by the percentage of top growth represented by the stalks (tables 7 and 8). Weights of stalks showed a similar trend (see table 14).

TABLE 7.—*Average area and moist and oven-dry weights of cured leaves per plant, moist and oven-dry weights per square foot of cured leaves, percentage of moisture absorbed by leaves when exposed to constant temperature and moisture conditions, and weights of stalks of Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1936–38*

[Measurements made at 88 percent relative humidity and 77° F. on leaves from 24 plants comprising 2 rows, or one-third, of each plot in series B; the lower, middle, and top leaf groups usually consisted of 5 or 6 leaves per plant]

Plant part and treatment No.	Water treatment				Average area per plant	Moist weight	Oven-dry weight	Moisture	Moist weight per square foot	Oven-dry weight per square foot
	Precipitation		Irrigation							
	Early	Late	Early	Late						
					Square feet	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*
Lower leaves:										
1	Without	Without	Without	Without	3.31	21.99	17.73	19.37	6.64	5.36
2	With	With	With	With	5.47	30.84	24.59	20.27	5.64	4.50
3	do	Without	do	Without	5.46	30.50	23.75	22.13	5.59	4.35
4	Without	With	Without	With	4.06	26.05	20.45	21.50	6.42	5.04
5	With	do	do	Without	4.64	27.36	21.61	21.02	5.90	4.66
Middle leaves:										
1	Without	Without	do	do	5.16	36.00	28.37	21.19	6.98	5.50
2	With	With	With	With	8.16	52.06	41.17	20.92	6.38	5.05
3	do	Without	do	Without	8.47	51.24	39.57	22.78	6.05	4.67
4	Without	With	Without	With	7.13	43.45	33.56	22.76	6.09	4.71
5	With	do	do	Without	7.28	47.05	36.64	22.13	6.46	5.03
Top leaves:										
1	Without	Without	do	do	2.62	22.93	17.56	23.42	8.75	6.70
2	With	With	With	With	4.56	35.68	27.54	22.81	7.82	6.04
3	do	Without	do	Without	4.95	35.59	26.97	24.22	7.19	5.45
4	Without	With	Without	With	4.88	36.63	27.37	25.28	7.51	5.61
5	With	do	do	Without	4.27	32.52	24.74	23.92	7.62	5.79
All leaves:										
1	Without	Without	do	do	11.09	80.92	63.66	21.33	7.30	5.74
2	With	With	With	With	18.19	118.58	93.30	21.32	6.52	5.13
3	do	Without	do	Without	18.88	117.33	90.29	23.05	6.21	4.78
4	Without	With	Without	With	16.07	106.13	81.38	23.32	6.60	5.06
5	With	do	do	Without	16.19	106.93	82.99	22.39	6.60	5.13
					Percent [2]					
Stalks: [1]										
1	Without	Without	do	do	37.53	52.77	38.25	27.52	-------	-------
2	With	With	With	With	48.76	115.08	88.81	22.83	-------	-------
3	do	Without	do	Without	42.96	89.33	68.01	23.87	-------	-------
4	Without	With	Without	With	40.65	74.92	55.73	25.61	-------	-------
5	With	do	do	Without	46.08	92.87	70.91	23.65	-------	-------

[1] Stalk weights are averages for 1937 and 1938.
[2] Percent of top (above-ground portion harvested).

The roots did not receive complete study, but among those studied there were decided differences in development (fig. 4). The roots of five plants from each treatment of the 1939 crop were washed out of the soil by a stream of water from a hose, and the average air-dry weights were determined (table 8). There were very few fibrous roots on plants grown on the area held dry all season (treatment 1), but abundant fibrous roots were evident where the plants were irrigated. Since it was not practical to wash out all the roots throughout their entire length, it was not possible to determine the effect of soil-water relations on root length.

TABLE 8.—*Average area and moist and oven-dry weights of cured leaves per plant, moist and oven-dry weights per square foot of cured leaves, percentage of moisture absorbed by leaves when exposed to constant temperature and moisture conditions, and weights of stalks and roots of Maryland Medium Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1939*

Measurements made at 88 percent relative humidity and 77° F. on leaves from 24 plants comprising 2 rows, or one-third, of plants for each treatment; the lower, middle, and top leaf groups usually consisted of 5 or 6 leaves per plant]

Plant part and treatment No.	Water treatment				Average area per plant	Moist weight	Oven-dry weight	Moisture	Moist weight per square foot	Oven-dry weight per square foot
	Precipitation		Irrigation							
	Early	Late	Early	Late						
					Square feet	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*
Lower leaves:										
1	Without	Without	Without	Without	3.34	23.37	18.91	19.08	7.00	5.66
2	With	With	With	With	4.93	33.95	26.54	21.83	6.89	5.38
3	do	Without	do	Without	5.23	34.91	27.24	21.97	6.67	5.21
4	Without	With	Without	With	3.84	29.75	23.78	20.07	7.75	6.19
5	With	do	do	Without	4.35	32.21	25.19	21.80	7.40	5.79
Middle leaves:										
1	Without	Without	do	do	3.28	27.06	21.27	21.40	8.25	6.48
2	With	With	With	With	4.54	32.91	25.36	22.94	7.25	5.59
3	do	Without	do	Without	5.32	38.68	29.71	23.19	7.27	5.58
4	Without	With	Without	With	3.79	31.88	24.81	22.18	8.41	6.55
5	With	do	do	Without	4.66	35.41	27.13	23.38	7.60	5.82
Top leaves:										
1	Without	Without	do	do	1.82	16.60	12.89	22.35	9.12	7.08
2	With	With	With	With	3.72	29.96	22.81	23.87	8.05	6.13
3	do	Without	do	Without	3.82	30.34	23.07	23.96	7.94	6.04
4	Without	With	Without	With	2.73	22.84	17.55	23.16	8.37	6.43
5	With	do	do	Without	3.59	29.48	22.44	23.88	8.21	6.25
All leaves:										
1	Without	Without	do	do	8.44	67.03	53.07	20.83	7.94	6.29
2	With	With	With	With	13.19	96.82	74.71	22.84	7.34	5.66
3	do	Without	do	Without	14.37	103.93	80.02	23.01	7.23	5.57
4	Without	With	Without	With	10.36	84.47	66.14	21.70	8.15	6.38
5	With	do	do	Without	12.60	97.10	74.76	23.01	7.71	5.93
					Percent [1]					
Stalks:										
1	Without	Without	do	do	37.35	.....	31.64	.....	.....	.....
2	With	With	With	With	43.64	.....	57.84	.....	.....	.....
3	do	Without	do	Without	40.61	.....	54.72	.....	.....	.....
4	Without	With	Without	With	31.96	.....	31.07	.....	.....	.....
5	With	do	do	Without	41.88	.....	53.87	.....	.....	.....
Roots:										
1	Without	Without	do	do	.....	106.00	21.40	79.81	.....	.....
2	With	With	With	With	.....	314.00	63.90	79.65	.....	.....
3	do	Without	do	Without	.....	298.00	69.50	76.68	.....	.....
4	Without	With	Without	With	.....	181.00	33.60	81.44	.....	.....
5	With	do	do	Without	.....	193.00	37.40	80.62	.....	.....

[1] Percent of top (above-ground portion harvested).

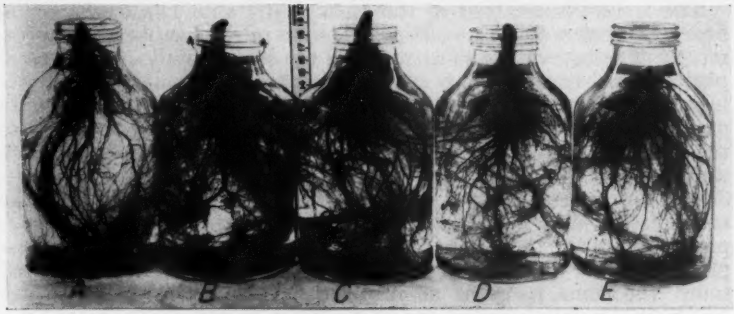

FIGURE 4.—Tobacco roots typical of those produced in irrigation series: *A*, Without rainfall or supplemental water during the entire period of growth; *B*, with rainfall and supplemental water throughout period of growth; *C*, with rainfall and supplemental water during early period of growth, but without either during late period of growth; *D*, without rainfall or supplemental water during early period of growth, but with both rainfall and supplemental water during late period of growth; *E*, with rainfall only during entire period of growth. Photographed October 1939.

BIOCHEMICAL STUDIES

The results presented in tables 9 and 10 are based on samples taken from series A (lowland) and B (upland) and represent average values corrected for the sand and other siliceous soil material adhering to the leaves. In most details the results from the two series agree as to effects produced by irrigation. The areas of leaves with midribs removed were determined by tracing on manila wrapping paper, measuring the total area of the paper, cutting out and weighing the leaf tracings, and calculating the areas on the basis of weight relations. The water supplied definitely increased the leaf area, green and oven-dry weights per leaf, water content, and green weight per square foot (table 9). These increases were as a rule directly related to the amount of water supplied by irrigation. The oven-dry weight per square foot in general was inversely related to the amount of water supplied. Much the same relations are apparent in table 10. The treatments for 1935 did not include a differential rate of irrigation, but did include differences in time of application. Withholding the water for 3 weeks prior to harvest (treatment 3, table 10) resulted in leaf weighing less per unit area than that from any other treatment represented, agreeing with the results presented in tables 7 and 8. However, in this instance the weight was much less since the results were corrected for sand and other siliceous soil material and the midrib weight was not included in the total area weight from which the calculations were made. It is interesting to note that the green weight per square foot of leaf area was lower in the area where water was withheld than in the area where water was added, supporting the values in the next column showing a greater weight per square foot of oven-dry material. This difference apparently was largely water, as the leaf showed a lower percentage of water. These differences became more pronounced as the season advanced; the August 23 samples show a wider difference than the July 23 samples.

764540—47——3

The results of analysis of the 1935 crop (table 11) are based on averages from series A and B, which were in reasonably close agreement. The percentage of nitrogen in the leaves, stalks, and tops of plants grown in areas from which water was withheld was definitely higher than in plants from areas supplied with water during early growth. However, the highest percentage of nitrogen was found in the leaves, stalks, and tops of plants grown on the area from which water was withheld early in the season and supplied during the last 3 weeks of growth (treatment 4). In fact, the percentages of all the ash constituents except sulfur were highest when the water was supplied only during the late period of growth. The percentage of phosphoric acid (P_2O_5), although low regardless of treatment, showed much the same relations as nitrogen. The percentage of potash (K_2O) was definitely lower in the leaves of plants grown in the area from which water was withheld than in areas where it was supplied, but the leaf grown under the late irrigations showed the highest content of this constituent. This increase in potash cannot be accounted for by the potash content of the water applied, as analysis of the water showed less than 4 pounds of K_2O applied per acre where supplemental water was supplied throughout the season. The data

TABLE 9.—*Average leaf area, green and oven-dry weights per leaf, water content, green and oven-dry weights per square foot of leaves from plants of Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1934*

Samples consisted of 15 half leaves taken from 2 groups of 15 plants so as to avoid severe mutilation of plants values shown are averages from series A and B corrected for adhering sand and other siliceous soil material

Date, leaf,[1] and treatment No.	Water treatment		Average leaf			Water	Green weight per square foot	Oven-dry weight per square foot
	Precipitation	Irrigation	Area	Green weight	Oven-dry weight			
July 31 (seventh leaf):			*Square feet*	*Grams*	*Grams*	*Percent*	*Grams*	*Grams*
1	Without	Without	0.71	16.58	2.05	87.64	23.35	2.89
2	With	¼ inch twice weekly	.76	19.66	2.43	87.74	25.87	3.20
3	do	½ inch twice weekly	.80	20.55	2.41	88.27	25.69	3.01
August 6 (seventh leaf):								
1	Without	Without	.78	17.59	2.55	85.50	22.55	3.27
2	With	¼ inch twice weekly	1.01	25.71	3.88	84.91	25.46	3.84
3	do	½ inch twice weekly	1.29	34.00	4.66	86.29	26.36	3.61
August 14 (eighth leaf):								
1	Without	Without	.88	20.32	2.67	86.86	23.09	3.03
2	With	¼ inch twice weekly	1.07	27.51	3.33	87.90	25.71	3.11
3	do	½ inch twice weekly	1.15	30.20	3.45	88.58	26.26	3.00
August 21 (eighth leaf):								
1	Without	Without	.87	18.66	2.64	85.85	21.45	3.03
2	With	¼ inch twice weekly	1.25	30.67	3.93	87.19	24.54	3.14
3	do	½ inch twice weekly	1.58	40.63	4.52	88.88	25.72	2.86
August 28 (ninth leaf):								
1	Without	Without	.97	22.29	3.16	85.82	22.98	3.26
2	With	¼ inch twice weekly	1.23	31.03	3.76	87.88	25.23	3.06
3	do	½ inch twice weekly	1.45	37.41	4.07	89.12	25.80	2.81
September 6 (ninth leaf):								
1	Without	Without	.89	18.32	2.94	83.95	20.58	3.30
2	With	¼ inch twice weekly	1.38	31.57	4.60	85.43	22.88	3.33
3	do	½ inch twice weekly	1.72	42.87	4.91	88.55	24.92	2.85

[1] Leaves numbered from bottom of plant.

thus indicate an important influence of water upon the availability to the tobacco plant of relatively insoluble soil potash. The percentages of lime and magnesia were increased by withholding water, but the reverse appears to be true of sulfur. However, when water was added late in the season the percentages of lime and magnesia were increased. The plants from the control treatment tended to approach those that received the late additions of water in percentage content of the various constituents. The percentage of total ash content was lowest in the leaf of plants grown where water was supplied throughout the growing period and highest where water was supplied during the last 3 weeks prior to harvest. These same relations prevailed for the stalks and consequently for the tops, including leaf and stalk.

The actual recovery values for ash constituents (pounds per acre) were related much the same as the percentage values were

TABLE 10.—*Average leaf area, green and oven-dry weights per leaf, water content, green and oven-dry weights per square foot of leaves from plants of Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1935*

Samples consisted of 15 half leaves taken from 2 groups of 15 plants so as to avoid severe mutilation of plants; values shown are averages for series A and B corrected for adhering sand and other siliceous soil material]

Date, leaf,[1] and treatment No.	Water treatment				Average leaf			Water	Green weight per square foot	Oven-dry weight per square foot
	Precipitation		Irrigation		Area	Green weight	Oven-dry weight			
	Early	Late	Early	Late						
					Square feet	*Grams*	*Grams*	*Per-cent*	*Grams*	*Grams*
July 23 (seventh leaf):										
1	Without	Without	Without	Without	0.49	10.73	1.82	83.04	21.90	3.71
2	With	With	With	With	.67	15.76	2.25	85.72	23.52	3.36
3	do	Without	do	Without	.73	16.71	2.41	85.58	22.89	3.30
4	Without	With	Without	With	.54	11.71	1.94	83.43	21.69	3.59
5	With	do	do	Without	.77	18.71	2.72	85.46	24.30	3.53
July 30 (seventh leaf):										
1	Without	Without	do	do	.59	14.08	2.68	80.97	23.86	4.54
2	With	With	With	With	.88	21.83	3.46	84.15	24.81	3.93
3	do	Without	do	Without	.93	23.33	3.69	84.18	25.09	3.97
4	Without	With	Without	With	.59	13.44	2.49	81.47	22.78	4.22
5	With	do	do	Without	.96	24.80	3.87	84.40	25.83	4.03
August 6 (eighth leaf):										
1	Without	Without	do	do	.62	14.16	2.82	80.08	22.84	4.55
2	With	With	With	With	1.13	28.90	4.39	84.81	25.58	3.88
3	do	Without	do	Without	1.05	26.43	4.12	84.41	25.17	3.92
4	Without	With	Without	With	.63	14.15	2.70	80.92	22.46	4.29
5	With	do	do	Without	1.09	26.88	4.10	84.75	24.66	3.76
August 13 (eighth leaf):										
1	Without	Without	do	do	.66	15.22	2.93	80.75	23.06	4.44
2	With	With	With	With	1.08	26.50	3.97	85.02	24.54	3.68
3	do	Without	do	Without	1.06	24.89	3.74	84.97	23.48	3.53
4	Without	With	Without	With	.58	13.56	2.62	80.68	23.38	4.52
5	With	do	do	Without	1.05	25.49	3.90	84.70	24.28	3.71
August 23 (ninth leaf):										
1	Without	Without	do	do	.70	15.92	3.20	79.90	22.74	4.57
2	With	With	With	With	1.28	31.34	4.62	85.26	24.48	3.61
3	do	Without	do	Without	1.14	26.66	3.84	85.60	23.39	3.37
4	Without	With	Without	With	.85	21.29	3.34	84.31	25.05	3.93
5	With	do	do	Without	1.24	31.37	4.70	85.02	25.30	3.79

[1] Leaves numbered from bottom of plant.

TABLE 11.—*Average weight per plant, content and recovery per acre of the different plant-food constituents, and content and yield of nicotine from Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1935*

[Determinations based upon 15 sample plants from each of series A and B; values are averages on a moisture-free basis and corrected for sand and other siliceous soil material]

Plant part and treatment No.	Water treatment				Average weight per plant	Content							
	Precipitation		Irrigation			Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	Nicotine
	Early	Late	Early	Late									
Leaves:					*Grams*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Without	Without	Without	Without	31.70	14.85	2.57	0.62	4.40	3.29	0.75	0.69	1.36
2	With	With	With	With	56.04	14.75	2.16	.51	5.07	3.17	.64	1.00	.75
3	do	Without	do	Without	43.84	16.08	2.10	.53	5.55	3.10	.56	.92	.76
4	Without	With	Without	With	50.94	18.83	3.25	.67	5.67	4.27	.84	.88	.99
5	With	do	do	Without	59.78	16.01	2.54	.58	5.33	3.32	.71	.93	1.05
Stalks:													
1	Without	Without	do	do	17.83	8.63	2.67	.67	3.89	1.09	.41	.31	.37
2	With	With	With	With	53.89	7.88	2.32	.65	3.60	.94	.34	.39	.25
3	do	Without	do	Without	40.50	8.68	2.53	.70	3.90	1.04	.34	.44	.30
4	Without	With	Without	With	30.49	12.07	3.45	.81	5.75	1.37	.44	.40	.37
5	With	do	do	Without	50.93	8.52	2.79	.66	3.89	.97	.38	.38	.31
Tops (leaves and stalks):													
1	Without	Without	do	do	49.54	12.64	2.60	.64	4.21	2.51	.62	.56	1.02
2	With	With	With	With	109.93	11.38	2.24	.57	4.35	2.08	.50	.70	.52
3	do	Without	do	Without	84.34	12.54	2.31	.61	4.76	2.11	.46	.69	.54
4	Without	With	Without	With	81.43	16.30	3.33	.72	5.71	3.31	.69	.70	.75
5	With	do	do	Without	110.71	12.57	2.66	.61	4.67	2.24	.56	.67	.72

Plant part and treatment No.	Water treatment				Recovery per acre							Nicotine yield per acre
	Precipitation		Irrigation		Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	
	Early	Late	Early	Late								
					Pounds	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
Leaves:												
1	Without	Without	Without	Without	56.47	9.72	2.34	16.79	12.48	2.80	2.57	5.11
2	With	With	With	With	99.18	14.47	3.35	34.00	21.41	4.29	6.67	5.15
3	do	Without	do	Without	84.78	11.10	2.70	29.21	16.45	2.94	4.83	3.97
4	Without	With	Without	With	114.88	19.93	4.06	34.67	26.05	5.04	5.38	6.00
5	With	do	do	Without	114.44	18.18	4.10	38.07	23.76	5.03	6.58	7.54
Stalks:												
1	Without	Without	do	do	18.28	5.71	1.42	8.34	2.24	.82	.62	.80
2	With	With	With	With	50.96	14.97	4.10	23.25	6.17	2.17	2.54	1.58
3	do	Without	do	Without	42.73	12.50	3.36	19.17	5.17	1.69	2.17	1.49
4	Without	With	Without	With	43.98	12.55	2.95	20.96	4.97	1.61	1.43	1.34
5	With	do	do	Without	51.98	16.96	4.00	23.74	5.86	2.31	2.25	1.88
Tops (leaves and stalks):												
1	Without	Without	do	do	74.75	15.43	3.76	25.13	14.72	3.62	3.19	5.91
2	With	With	With	With	150.14	29.44	7.45	57.25	27.58	6.46	9.21	6.73
3	do	Without	do	Without	127.49	23.60	6.06	48.38	21.62	4.63	7.00	5.46
4	Without	With	Without	With	158.86	32.48	7.01	55.63	31.02	6.65	6.81	7.34
5	With	do	do	Without	166.42	35.14	8.10	61.81	29.62	7.34	8.83	9.42

Plant part and treatment No.	Water treatment				Area	Weight per square foot								
	Precipitation		Irrigation			Dry matter	Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	Nicotine
	Early	Late	Early	Late										
					Square feet	*Grams*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*
Leaves:														
1	Without	Without	Without	Without	5.55	5.819	0.863	0.149	0.036	0.255	0.191	0.043	0.040	0.079
2	With	With	With	With	11.04	5.072	.750	.109	.025	.257	.162	.032	.051	.039
3	do	Without	do	Without	9.45	4.653	.747	.098	.024	.258	.143	.026	.043	.036
4	Without	With	Without	With	10.96	4.645	.875	.151	.031	.263	.198	.039	.041	.046
5	With	do	do	Without	11.15	5.364	.858	.137	.031	.285	.179	.038	.049	.057

(table 11). However, there was one notable exception: the greatest recovery of total ash and most constituents that make up the ash took place in plants on the control plot. The lowest took place consistently where the soil was held dry during the entire period (treatment 1). However, on the basis of recovery per square foot of leaf surface, the leaves grown under the dry condition early in the season showed higher recovery of all constituents except potash and sulfur than those grown under other treatments.

The results of the analysis of the 1936 crop from series B (table 12) showed much the same relations as those for 1935 (table 11). The crop grown under dry conditions (treatment 1) had the highest percentage of nitrogen and the greatest content per unit area of leaf, but a lower recovery in pounds per acre than the crop that received treatment 5 because of the small size of the plants. The percentage of potash was about the same in the leaf produced on the control plot as in that grown under irrigation, but the highest total recovery in pounds per acre took place where supplemental water was added. Again, the lowest recovery in pounds per acre took place in plants grown where water was withheld. The main difference appears to be one of size of plant rather than increased percentage of any constituent. The exceptions to this generalization were the highest percentage of nitrogen in leaf of plants grown for the entire period with low soil water (treatment 1) and the lowest percentage of nitrogen in the leaf grown under irrigation (treatment 2), apparently the result of leaching from the soil.

In both 1935 and 1936 the percentages of nicotine in the leaf and stalk of plants grown without water (treatment 1) were distinctly higher than in those of plants grown with irrigation throughout the season. Nicotine content per unit area of leaf was also highest in plants grown without water. The application of water late in the season produced a higher percentage of nicotine as well as a larger amount per square foot of leaf area than other irrigation treatments. The percentage of nicotine was lowest where there was continuous irrigation. These comparisons seem to bear some relation to the nitrogen content. The yields of nicotine on the acre basis did not show the same relation to the treatments that the percentages did because of compensation in size of plants.

Some studies were made to determine the effect of irrigation on the organic constituents of tobacco (table 13). In the late stages of growth starch and sucrose were definitely higher in the leaf grown under dry conditions (treatment 1) than in that grown with abundant moisture (treatment 2). Leaf composition of control plants was similar to that of leaf subjected to treatment 1. There was apparently a difference in the content of reducing sugars.

YIELDS, VALUE, AND QUALITY OF THE CROP

The yields and value of the crop are in the last analysis the best tangible measure of the product. The crop must be acceptable to the trade to become an economic factor in agriculture. It is not always possible or easy to obtain a true picture of yield and value relations, but carefully conducted tests for a period of years offer the best available approach. The results presented in table 14 show striking

TABLE 12.—*Average weight per plant, content and recovery per acre of the different plant-food constituents, and content and yield of nicotine from Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1936*

[Determinations based upon 24 sample plants from series B (moisture-free basis and corrected for sand and other siliceous soil material)]

Plant part and treatment No.	Water treatment				Average weight per plant	Content							
	Precipitation		Irrigation			Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	Nicotine
	Early	Late	Early	Late									
Leaves:					*Grams*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Without	Without	Without	Without	40.93	17.01	3.93	0.57	5.25	4.02	1.01	0.54	2.10
2	With	With	With	With	79.79	18.46	2.02	.53	6.76	3.76	.80	.70	1.39
5	do	do	Without	Without	69.90	17.84	2.81	.57	7.04	3.09	.94	.63	1.92
Stalks:													
1	Without	Without	do	do	23.58	10.09	2.99	.54	4.85	1.18	.39	.23	.44
2	With	With	With	With	65.62	9.79	2.49	.69	4.86	.97	.35	.31	.39
5	do	do	Without	Without	50.99	10.10	3.08	.69	5.20	.85	.40	.29	.47
Tops (leaves and stalks):													
1	Without	Without	do	do	64.51	14.48	3.59	.56	5.10	2.98	.78	.43	1.49
2	With	With	With	With	145.41	14.55	2.23	.60	5.90	2.50	.60	.53	.93
5	do	do	Without	Without	120.89	14.58	2.92	.62	6.26	2.15	.71	.48	1.31

Plant part and treatment No.	Water treatment				Recovery per acre							
	Precipitation		Irrigation		Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	Nicotine yield per acre
	Early	Late	Early	Late								
Leaves:					*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	Without	Without	Without	Without	133.24	19.28	2.80	25.70	19.66	4.94	2.64	10.27
2	With	With	With	With	281.92	19.24	5.01	64.47	35.92	7.67	6.75	13.20
5	do	do	Without	Without	228.75	23.44	4.72	58.88	25.90	7.81	5.27	16.08
Stalks:												
1	Without	Without	do	do	45.54	8.44	1.51	13.69	3.34	1.11	.66	1.23
2	With	With	With	With	122.96	19.56	5.47	38.10	7.60	2.77	2.46	3.01
5	do	do	Without	Without	94.46	18.83	4.21	31.71	5.14	2.42	1.73	2.85
Tops (leaves and stalks):												
1	Without	Without	do	do	178.78	27.72	4.31	39.39	23.00	6.05	3.30	11.50
2	With	With	With	With	404.88	38.80	10.48	102.57	43.52	10.44	9.21	16.21
5	do	do	Without	Without	323.21	42.27	8.93	90.59	31.04	10.23	7.00	18.93

TABLE 12.—*Average weight per plant, content and recovery per acre of the different plant-food constituents, and content and yield of nicotine from Maryland Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1936*—Continued

Plant part and treatment No.	Water treatment				Weight per square foot								
	Precipitation		Irrigation		Dry matter	Total ash	Nitrogen (N)	Phosphoric acid (P_2O_5)	Potash (K_2O)	Lime (CaO)	Magnesia (MgO)	Sulfur (S)	Nicotine
	Early	Late	Early	Late									
Leaves:					*Grams*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*	*Gram*
1	Without	Without	Without	Without	5.278	0.897	0.208	0.030	0.277	0.212	0.053	0.028	0.111
2	With	With	With	With	5.077	.937	.102	.027	.343	.191	.041	.036	.070
5	do	do	Without	Without	4.890	.872	.137	.028	.344	.151	.046	.031	.094

TABLE 13.—*Average area, green weight, dry weight, moisture content, dry matter per square foot, and percentage of starch, reducing sugars, and sucrose of leaves of Maryland Medium Broadleaf tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1939*

Date and treatment No.	Water treatment				Average leaf area	Average green weight [1]	Average dry weight [1]	Total moisture [1]	Dry matter per square foot [1]	Green basis [1]		
	Precipitation		Irrigation							Starch	Reducing sugars	Sucrose
	Early	Late	Early	Late								
					Square feet	*Grams*	*Grams*	*Percent*	*Grams*	*Percent*	*Percent*	*Percent*
Aug. 13:												
1A	Without	Without	Without	Without	0.80	17.94	2.66	85.18	3.33	0.97	0.47	0.25
2A	With	With	With	With	.97	24.39	3.54	85.49	3.64	1.11	.40	.24
5A	do	do	Without	Without	.91	21.68	3.33	84.64	3.68	.76	.67	.29
Aug. 28: [2]												
1A	Without	Without	do	do	.81	18.03	2.69	85.09	3.33	1.05	.26	.28
2A	With	With	With	With	1.11	26.61	3.55	86.64	3.20	1.68	.55	.26
5A	do	do	Without	Without	1.05	26.31	3.90	85.18	3.73	1.58	.41	.25
Sept. 14:												
1A	Without	Without	do	do	.71	16.31	2.83	82.65	4.01	2.50	.45	.36
2A	With	With	With	With	1.07	23.39	3.38	85.55	3.17	1.63	.51	.21
5A	do	do	Without	Without	1.07	25.94	4.09	84.24	3.81	2.02	.46	.34

Date and treatment No.	Water treatment				Moisture-free basis [1]			Weight per square foot of leaf area		
	Precipitation		Irrigation		Starch	Reducing sugars	Sucrose	Starch	Reducing sugars	Sucrose
	Early	Late	Early	Late						
					Percent	*Percent*	*Percent*	*Gram*	*Gram*	*Gram*
Aug. 13:										
1A	Without	Without	Without	Without	6.57	3.16	1.71	0.219	0.105	0.057
2A	With	With	With	With	7.66	2.78	1.63	.279	.101	.059
5A	do	do	Without	Without	4.97	4.35	1.90	.183	.160	.070
Aug. 28: [2]										
1A	Without	Without	do	do	7.03	1.73	1.91	.234	.058	.064
2A	With	With	With	With	12.55	4.08	1.94	.401	.131	.062
5A	do	do	Without	Without	10.67	2.73	1.71	.398	.102	.064
Sept. 14:										
1A	Without	Without	do	do	14.41	2.62	2.08	.578	.105	.083
2A	With	With	With	With	11.27	3.50	1.45	.357	.111	.046
5A	do	do	Without	Without	12.80	2.94	2.18	.488	.112	.083

[1] Corrected for sand and other siliceous soil material.
[2] Time of flowering and topping.

TABLE 14.—*Yields of leaf and stalk, gross values, and prices of tobacco grown with and without rainfall or supplemental water, Upper Marlboro, Md., 1935–40*

Series and treatment No.	Water treatment				Yield of leaf tobacco per acre						
	Precipitation		Irrigation		1935	1936	1937	1938	1939	1940	Average
	Early	Late	Early	Late							
Series A:					*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	Without	Without	Without	Without	788	782	876	650	400	438	656
2	With	With	With	With	738	1,076	936	745	810	813	853
3	do	Without	do	Without	682	851	960	738	800	751	797
4	Without	With	Without	With	926	1,013	876	750	675	751	832
5	With	do	do	Without	919	1,213	840	688	790	688	856
Series B:											
1	Without	Without	do	do	462	744	860	750	602	663	680
2	With	With	With	With	888	1,226	1,140	963	1,036	1,014	1,045
3	do	Without	do	Without	894	1,188	1,300	1,038	1,218	1,038	1,113
4	Without	With	Without	With	751	1,100	1,300	975	574	851	925
5	With	do	do	Without	869	1,125	1,200	1,000	1,036	913	1,024
Both series:											
1	Without	Without	do	do	625	763	868	700	501	551	668
2	With	With	With	With	813	1,151	1,038	854	923	914	949
3	do	Without	do	Without	788	1,020	1,130	888	1,009	895	955
4	Without	With	Without	With	839	1,057	1,088	863	625	801	879
5	With	do	do	Without	894	1,169	1,020	844	913	801	940

Series and treatment No.	Water treatment				Yield of tobacco stalks per acre						
	Precipitation		Irrigation		1935	1936	1937	1938	1939	1940	Average
	Early	Late	Early	Late							
Series A:					*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*	*Pounds*
1	Without	Without	Without	Without	381	375	616	400	240	238	375
2	With	With	With	With	569	763	960	638	660	688	713
3	do	Without	do	Without	431	538	768	531	560	575	567
4	Without	With	Without	With	488	538	752	475	370	450	512
5	With	do	do	Without	694	725	816	588	610	513	683

Series B:											
1	Without	Without	do	do	188	375	470	675	280	363	392
2	With	With	With	With	681	875	1,060	1,050	854	775	883
3	do	Without	do	Without	575	813	960	1,025	903	813	848
4	Without	With	Without	With	269	613	1,040	738	252	500	569
5	With	do	do	Without	569	650	910	700	728	625	697
Both series:											
1	Without	Without	do	do	285	375	543	538	260	301	384
2	With	With	With	With	625	819	1,010	844	757	732	798
3	do	Without	do	Without	503	676	864	778	732	694	708
4	Without	With	Without	With	379	576	896	607	311	475	541
5	With	do	do	Without	632	688	863	644	669	569	678

Series and treatment No.	Water treatment				Average proportion of leaf (1935–40)	Value of leaf tobacco per acre							Average price per pound (1935–40)
	Precipitation		Irrigation			1935	1936	1937	1938	1939	1940	Average	
	Early	Late	Early	Late									
Series A:					*Percent*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Dollars*	*Cents*
1	Without	Without	Without	Without	64	63	152	159	131	68	98	112	17.07
2	With	With	With	With	54	179	310	185	154	243	356	238	27.90
3	do	Without	do	Without	58	153	229	178	146	216	321	207	25.97
4	Without	With	Without	With	62	124	221	121	137	116	217	156	18.75
5	With	do	do	Without	57	227	362	179	128	191	273	227	26.52
Series B:													
1	Without	Without	do	do	63	25	141	76	167	83	188	113	16.62
2	With	With	With	With	54	225	423	277	240	288	428	314	30.05
3	do	Without	do	Without	57	270	410	184	251	295	465	313	28.12
4	Without	With	Without	With	62	90	293	134	210	40	171	156	16.86
5	With	do	do	Without	60	201	320	223	272	237	340	236	25.98
Both series:													
1	Without	Without	do	do	64	44	147	118	149	76	143	113	16.92
2	With	With	With	With	54	202	367	231	197	266	392	276	29.08
3	do	Without	do	Without	57	212	320	181	199	256	393	260	27.23
4	Without	With	Without	With	62	107	257	128	174	78	194	156	17.75
5	With	do	do	Without	58	214	341	201	200	214	307	246	26.17

and consistent differences in yield and gross value per acre of tobacco. These differences were the result of variation in rainfall and additions of supplemental water to the field-grown crop. There necessarily are variations in the results from year to year and between the two soils, but the yields and values obtained show somewhat the same relations each year.

Possibly the most notable variations were shown by tobacco grown on the control plot under normal rainfall (fig. 5, *A*); sometimes the yield was as large and the value as great as for crops produced with additional water. However, this is to be expected, since under ideal distribution of rainfall the results from the control treatment could even exceed those obtained from irrigation, as the excess water might cause

FIGURE 5.—Tobacco grown (*A*) under prevailing rainfall and (*B*) without rainfall or supplementary water. Border plants were removed just prior to harvest. The scaffolding shown was for the support of the canvas. Photographed August 26, 1936.

leaching and reduce the yields and values; if the season were unusually dry, however, the results might approach those from area 1, which received no water from rainfall or irrigation. The highest average value was obtained by the addition of supplemental water as required throughout the growing season (fig. 6, *A*); the highest yield and the next highest value were obtained for tobacco from the plot where water was withheld late in the season. The control plot gave the next highest average yield and value. This was followed by those of the plot which received water only late in the season. The lowest yields and values were obtained from area 1 from which water was withheld during the entire growing period. These same relations are evident in the average price per pound; the highest price obtained was for the leaf from the irrigated plot.

The stalk yields showed much the same relations as the leaf yields, but the highest percentage of leaf was found with the lowest yields (treatments 1 and 4) and the lowest percentage of leaf was found with the highest yields (treatments 2 and 3). Although a large stalk is not

desirable, it appears that with the present varieties the stalk yield increased out of proportion to the leaf yields.

The average value of the crop for the years covered by the test indicates that there is no great advantage in using supplemental water in addition to normal rainfall. It should be pointed out that the rainfall was usually adequate during the years covered by the test; however, if such a season as 1930 or 1943 had occurred, the results from irrigation would have been more striking. It seems to be clear that a higher quality product is consistently produced, as indicated by the average price per pound, by the use of irrigation as a supplement to natural rainfall. If economic conditions should change so that high-quality leaf would demand a greater premium, the use of

FIGURE 6.—Tobacco grown (*A*) with prevailing rainfall and supplementary water when required and (*B*) with the prevailing rainfall as the only source of water. Photographed August 26, 1936.

irrigation might be more profitable. These relations are further brought out in table 15, in which percentage of leaf for each grade is shown. These grades do not represent equal samples, but they indicate quality relationships. The high percentage of dull, or tip, grade indicates immaturity of leaf (treatments 1 and 4).

It is generally recognized by the trade that good fire-holding capacity is a prime requisite of Maryland tobacco. The high quality of the leaf produced as a result of irrigation is well illustrated by table 16, in which the fire-holding capacity is shown. The leaf produced on the plot kept dry during the entire period showed a low fire-holding capacity, as did the leaf grown on the plot that got late irrigation. There was apparently some reduction in fire-holding capacity of the leaf produced on the area kept dry for only 2 to 3 weeks before harvest. Where supplemental water was added throughout the period of growth, the leaf showed the highest fire-holding capacity. As was to be expected, the leaf grown on the control area

TABLE 15.—*Proportion of leaf tobacco in each farm grade in crops grown with and without rainfall and supplemental water, Upper Marlboro, Md., 1935–40*

Series and treatment No.	Water treatment				Bright (middle leaves)						
	Precipitation		Irrigation								
	Early	Late	Early	Late	1935	1936	1937	1938	1939	1940	Average[1]
Series A:					*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Without	Without	Without	Without	53	37	41	40	40	54	44
2	With	With	With	With	54	50	50	52	62	66	55
3	do	Without	do	Without	53	49	35	47	50	63	49
4	Without	With	Without	With	51	47	41	33	44	62	47
5	With	do	do	Without	56	56	43	45	58	58	53
Series B:											
1	Without	Without	do	do	45	39	40	47	40	62	45
2	With	With	With	With	59	66	58	52	55	63	59
3	do	Without	do	Without	58	61	52	53	49	67	57
4	Without	With	Without	With	50	52	34	44	35	46	43
5	With	do	do	Without	53	51	55	55	50	68	55
Both series:[1]											
1	Without	Without	do	do	50	38	40	43	40	59	44
2	With	With	With	With	57	59	54	52	58	64	58
3	do	Without	do	Without	56	56	45	51	50	66	53
4	Without	With	Without	With	51	50	37	39	40	53	45
5	With	do	do	Without	55	54	50	51	54	64	54

Series and treatment No.	Water treatment				Seconds (lower leaves)						
	Precipitation		Irrigation								
	Early	Late	Early	Late	1935	1936	1937	1938	1939	1940	Average[1]
Series A:					*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
1	Without	Without	Without	Without	21	20	14	16	22	23	19
2	With	With	With	With	23	23	15	16	24	22	21
3	do	Without	do	Without	24	22	15	17	23	22	20
4	Without	With	Without	With	15	18	14	20	23	20	18
5	With	do	do	Without	17	18	21	21	22	26	20

Series B:											
1	Without	Without	do	do	23	20	16	30	16	19	21
2	With	With	With	With	19	14	16	19	19	14	17
3	do	Without	do	Without	20	13	14	17	20	16	16
4	Without	With	Without	With	18	16	14	20	20	13	17
5	With	do	do	Without	18	16	15	18	16	18	17
Both series: [1]											
1	Without	Without	do	do	22	20	15	24	19	21	20
2	With	With	With	With	21	18	16	18	21	17	18
3	do	Without	do	Without	21	17	14	17	21	18	18
4	Without	With	Without	With	16	17	14	20	22	16	17
5	With	do	do	Without	17	17	18	19	19	21	18

Series and treatment No.	Water treatment				Dull (top leaves)						
	Precipitation		Irrigation								
	Early	Late	Early	Late	1935	1936	1937	1938	1939	1940	Average [1]
					Percent	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*	*Percent*
Series A:											
1	Without	Without	Without	Without	26	43	45	44	38	23	37
2	With	With	With	With	23	27	35	32	14	12	24
3	do	Without	do	Without	23	29	50	36	27	15	31
4	Without	With	Without	With	34	35	45	47	33	18	35
5	With	do	do	Without	27	26	36	34	20	16	27
Series B:											
1	Without	Without	do	do	32	41	44	23	44	19	34
2	With	With	With	With	22	20	26	29	26	23	24
3	do	Without	do	Without	22	26	34	30	31	17	27
4	Without	With	Without	With	32	32	52	36	45	41	40
5	With	do	do	Without	29	33	30	27	34	14	28
Both series: [1]											
1	Without	Without	do	do	28	42	45	33	41	20	36
2	With	With	With	With	22	23	30	30	21	19	24
3	do	Without	do	Without	23	27	41	32	29	16	29
4	Without	With	Without	With	33	33	49	41	38	31	38
5	With	do	do	Without	28	29	32	30	27	15	28

[1] Calculated from original data.

was erratic in fire-holding capacity from season to season, but on the average it approached that of the leaf grown on the area irrigated throughout the season.

TABLE 16.—*Fire-holding capacity of leaf tobacco grown with and without rainfall and supplemental water, Upper Marlboro, Md., 1934–36 and 1938–39*

Series and treatment No.	Water treatment				Average duration of glow					
	Precipitation		Irrigation		1934	1935	1936	1938	1939	Average [1]
	Early	Late	Early	Late						
					Seconds	*Seconds*	*Seconds*	*Seconds*	*Seconds*	*Seconds*
Series A:										
1	Without	Without	Without	Without	3.8	4.7	9.3	3.5	6.0	5.9
2	With	With	With	With	13.3	26.1	37.4	19.7	11.0	23.6
3	do	Without	do	Without	33.5	13.1	28.8	12.1	7.1	15.3
4	Without	With	Without	With	-------	5.1	8.0	3.3	5.6	5.5
5	With	do	do	Without	-------	12.5	34.4	24.6	10.6	20.5
Series B:										
1	Without	Without	do	do	6.9	4.8	6.8	24.3	5.6	10.4
2	With	With	With	With	10.7	12.6	25.6	67.5	15.7	30.4
3	do	Without	do	Without	48.1	28.4	26.8	55.5	9.8	30.1
4	Without	With	Without	With	-------	10.1	6.9	37.6	7.2	15.5
5	With	do	do	Without	-------	7.4	16.6	87.4	5.9	29.3
Both series:										
1	Without	Without	do	do	5.4	4.8	8.1	13.9	5.8	8.2
2	With	With	With	With	12.0	19.4	31.5	43.6	13.4	27.0
3	do	Without	do	Without	40.8	20.8	27.8	33.8	8.5	22.7
4	Without	With	Without	With	-------	7.6	7.5	20.5	6.4	10.5
5	With	do	do	Without	-------	10.0	25.5	56.0	8.3	24.9

[1] 1934 results not included.

DISCUSSION

The studies to determine the effects of irrigation were carried out on typical tobacco soils of southern Maryland; the heavier soils of this section were not represented. In other words, these tests were conducted on light soils that are subject to the leaching common under field conditions. Heavy soils are generally poorly suited to the production of Maryland tobacco and many other types because waterlogging sometimes occurs. Irrigation, or the use of supplemental water, on heavy soils if followed by heavy rainfall might result in insufficient oxygen for proper root development; it might even cause destruction of the greater part of the functioning roots. The overhead irrigation system used in this experiment was preferred since it washes the leaves much as rainfall does and is the desirable method for use on light soils subject to leaching.

There is reason to believe that the leaf tobacco produced on the areas held dry for the entire period of growth was not the typical dry-season product, since it was grown under very extreme conditions. In dry seasons soil is usually wet for a time and then is extremely dry for a period longer than the 2 to 3 weeks prior to harvest that certain areas in these experiments were kept dry. It is also true that atmospheric humidity above the dry soil area was not reduced, whereas it would be reduced during a dry season. However, the addition of water late in the season to an area which had been held dry for 2 to 3 weeks before harvest resulted in the succulent immature or second growth which produced cured leaf of poor quality.

Anderson and his associates (*1, 2, 3*) recognized the effect of leaching where irrigation is practiced and used nitrates to offset it. It should be recognized that accurate control of supplies of nitrate as well as of all other nutrient relations is desirable, but such control is difficult if not impossible to attain under field conditions. It is chiefly these relations that produce responses in any field study of irrigation effects on growth of tobacco.

The effects of irrigation during the early part of the season or throughout it on weight per square foot of leaf area are consistent in that leaf produced on irrigated plots weighed less than that produced on plots from which water was withheld. This would appear to indicate a lower density per unit area, as the leaves were definitely larger. The striking and consistent effect of irrigation in increasing the potash content of the leaf may be a partial explanation of the high quality of the product. Previous work (*15*) had shown a product of higher quality where liberal potash applications were made.

The higher nicotine content of leaf produced under dry conditions would appear to contradict the results previously reported when tobacco was grown for studies of nicotine production (*14*). The earlier tests demonstrated that irrigation generally increased the nicotine content, other factors being equal. However, it should be pointed out that the tests under discussion were conducted on soils of low fertility, particularly low in nitrogen, whereas the previous tests were conducted on highly fertile soil.

The improvement in fire-holding capacity of the leaf associated with abundant moisture from rainfall and supplemental water throughout the growing period appears to be an established fact. Such leaves had a lower weight per unit area as well as a higher content of potash.

SUMMARY

Irrigation experiments with tobacco were carried out on liberally fertilized loamy sand and sandy loam, typical tobacco soils of southern Maryland. Precipitation was withheld by means of a movable canvas from one area and supplementary water was added when required to another area in an attempt to simulate dry- and wet-weather conditions simultaneously on adjacent areas. The treatments were continuous throughout the season on two areas and were reversed late in the season on two others. The responses in growth and composition of tobacco subjected to the four treatments were compared with those of tobacco subjected to the prevailing weather conditions on a fifth area.

A larger leaf with a lower weight per unit area was produced when irrigation was used as a supplement to rainfall during the early part of the season or throughout it. The leaf area per plant produced with irrigation was about 25 square feet for the Maryland Broadleaf variety and 21 square feet for the Maryland Medium Broadleaf variety; these values were approximately double those for leaves produced where water was withheld during most of the growing period.

The cured leaf from tobacco subjected to irrigation treatments absorbed a higher percentage of moisture when exposed in a constant-temperature and humidity room than did leaf grown under dry conditions.

The most outstanding differences in composition of leaf were the higher potash percentage in leaf from plants grown on irrigated areas and the higher nitrogen percentage in the leaf from plants grown under dry conditions throughout the growth period or during early growth. The leaf produced under dry conditions during early growth or throughout the growing period was also definitely higher in nicotine; the nicotine content paralleled the higher nitrogen content. The highest percentage of ash was found in the leaf produced on areas to which water was supplied during the last 2 to 3 weeks before harvest and the lowest ash in leaf produced on areas from which water was withheld for most of the growing period.

The average yield, value, and price per pound of leaf tobacco were consistently in favor of using supplemental water with rainfall rather than withholding both. The advantage from the use of supplemental water, when compared with rainfall only, did not show up so decisively or so consistently, since during the period covered by this test the rainfall was generally almost adequate for normal growth. Nevertheless, on the average, there was a small increase in value when supplemental water was used during the early part of the growing period and throughout it. Withholding water during the early part or throughout the growing period resulted in a leaf of poor quality associated with immaturity, as indicated by the high percentage of leaf in the dull, or tip, grade.

The fire-holding capacity of the leaf was strikingly and consistently improved by the use of supplemental water during early growth in addition to rainfall.

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EFFECT OF INITIAL ACIDITY ON CALCIUM AND MAGNESIUM REQUIREMENTS OF TOBACCO IN ASEPTIC CULTURE [1]

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INTRODUCTION

A great deal of investigational work has been done on the relation of acidity to the growth of plants. A summary by Russell [2] mentioned the fact that a slight degree of acidity is usually beneficial in solution culture. He continued with the statement: "In soils, on the other hand, plants make their best growth in neutral or nearly neutral conditions." Definite evidence is available, however, that this generalization is too broad and that acidity may or may not be beneficial in either growth medium.[3] A summary by Pettinger [4] seems to indicate that many soils suitable for good crop production are acid in character. These writers emphasized not acidity in itself, but its influence on availability of nutrients. Similar evidence was presented by Albrecht and Schroeder. [5] Arnon and Johnson [6] found in addition that an increase in calcium ions could compensate for decreased availability of calcium due to excessive acidity. Acidity of the growth medium, therefore, would seem to be only one of many factors influencing availability, and not the all-important factor it was first considered.

A brief study, therefore, has been made on the relation of acidity in the range pH 4 to 7 to the calcium and magnesium requirements of seedlings of Xanthi Turkish tobacco (*Nicotiana tabacum* L.) in aseptic culture under controlled environmental conditions. The absence of extraneous micro-organisms in such studies is not usually considered important, although no evidence for this assumption is known. The data obtained with increasing quantities of calcium and magnesium at several initial acidities of the nutrient solution are presented in the form of growth curves.

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[1] Received for publication January 27, 1947.

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EXPERIMENTAL PROCEDURE

Xanthi Turkish tobacco seedlings were grown on 50 cc. of a mineral-salt solution in 200-cc. Pyrex Erlenmeyer flasks under aseptic conditions. The temperature used was 25° C., and light of about 500 foot-candles was furnished by 3,500° white fluorescent lamps. The growth period was 28 days.

The mineral-salt solution consisted of water, 1,000 cc.; $Ca(NO_3)_2.4H_2O$, 1.444 gm.; $Mg.(NO_3)_2.6H_2O$, 0.318 gm.; K_2HPO_4, 0.366 gm.; $KHSO_4$, 0.085 gm.; and NH_4Cl, 0.072 gm. Separate stock solutions of calcium nitrate, magnesium nitrate, and potassium phosphate plus potassium bisulfate plus ammonium chloride in 20× concentration were used in the preparation of the mineral-salt solution. In preparing cultures with varying quantities of calcium ion, calcium nitrate was replaced with 1.039 gm. of sodium nitrate ($NaNO_3$) and calcium was added as the chloride. Magnesium nitrate, similarly, was replaced with 0.211 gm. of sodium nitrate in the study of magnesium concentrations. The base solution, therefore, contained nitrogen, 225 mg.; potassium, 189 mg.; phosphorus, 65 mg.; magnesium, 30 mg.; calcium, 245 mg.; and sulfur, 20 mg. per liter. Micronutrients, except for boron (H_3BO_3), were added to this solution as the chlorides. The quantities used were iron, 15 mg.; zinc, 0.5 mg.; copper, 0.125 mg.; manganese, 1.0 mg.; and boron, 0.5 mg. per liter. Acidity was adjusted with 0.1 N hydrochloric acid.

The composition of the mineral-salt solution was equivalent to that used by McMurtrey [7] in solution-culture studies with tobacco. It differed only in that potassium was increased from 125 to 189 mg. per liter and in that potassium nitrate, monopotassium phosphate, and magnesium sulfate were replaced with dipotassium phosphate and potassium bisulfate, the other salts being readjusted in concentration.

The cultures in the magnesium series contained 57.1 mg. of sodium ion per liter and those in the calcium series 281.1 mg. in addition to all the essential elements. Addition of hydrochloric acid for pH adjustment totaled not more than 28 mg. of chloride ion per liter, as compared with the 31 mg. originally present as ammonium chloride. Use of the chlorides of magnesium and calcium further increased the chloride-ion content by a maximum of 29.2 and 442.3 mg. per liter, respectively, depending on the particular concentration of magnesium or calcium ion employed.

The tobacco seeds were germinated in sterilized petri dishes containing a layer of blotting paper and several layers of filter paper. Seeds sterilized by immersion in 1:1,000 silver nitrate solution for 15 minutes were washed several times with sterile distilled water and then poured as a water suspension into the petri dishes. With a flamed platinum needle the seedlings were transferred to sterile Erlenmeyer flasks containing the nutrient medium and deposited on a double layer of filter paper held in a plant holder. This holder consisted of a glass rod 4 mm. in diameter which passed through the absorbent cotton in the neck of the flask and had a glass ring fused to its lower end. The filter-paper disks were held in this ring by means of a loose inner glass ring as shown in figure 1. The edges of the paper

[7] McMURTREY, J. E., Jr. DISTINCTIVE EFFECTS OF THE DEFICIENCY OF CERTAIN ESSENTIAL ELEMENTS ON THE GROWTH OF TOBACCO PLANTS IN SOLUTION CULTURES. U. S. Dept. Agr. Tech. Bul. 340, 43 pp., illus. 1933.

disks were bent down and forced between the rings to keep them in position and were then perforated. The purpose of the holder was

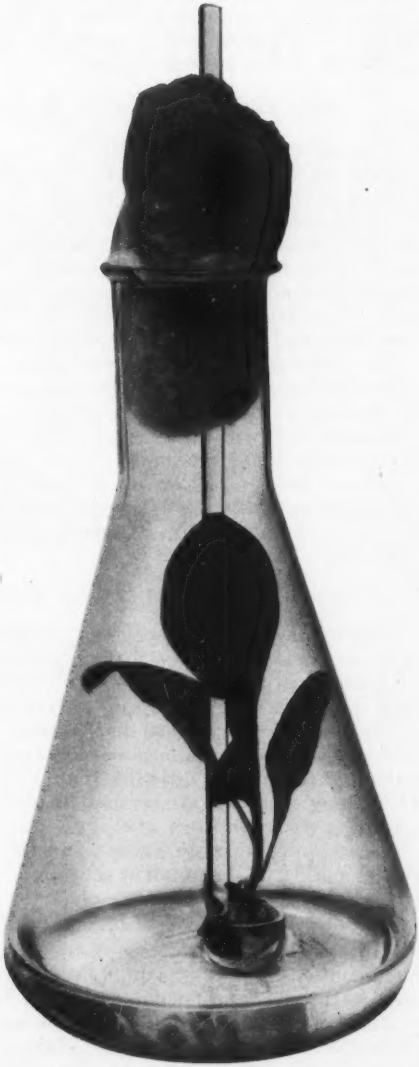

FIGURE 1.—Three-week-old seedling of Xanthi Turkish tobacco growing under aseptic conditions. A glass rod with fused-on ring passes through the absorbent-cotton plug. Two filter-paper disks, which are perforated with a needle after insertion in holder, are held in place in the ring by means of a loose inner glass ring, the edges of the paper disks being forced between the two rings.

to prevent contact of all but the roots of the plant with the solution. All glassware and media were sterilized at 15 pounds' pressure for 30 minutes.

At harvest the seedlings were washed, dried in the oven at 103° to 105° C. for 4 hours, cooled in the desiccator, and then weighed.

Two of the four duplicate seedlings were weighed together as a unit in each determination. Statistical methods appeared inapplicable, since it was necessary to reject about 10 percent of the seedlings because of contaminations with micro-organisms and unintentional injuries during transfer to the flasks. Some injured seedlings did not grow out of the cotyledon stage.

INFLUENCE OF ACIDITY ON CALCIUM REQUIREMENT

The effects obtained by varying the calcium content on the growth of the seedlings at four levels of acidity are shown in figure 2. The initial acidity levels were pH 6.48, 5.98, 5.42, and 4.39. Each value for dry weight is the average for eight seedlings, or for four in each of two determinations. The acidities at harvest were obtained by mixing the four residual solutions in each run and averaging the pH values in both runs. The averages found in this manner are not true pH values, but the deviations for the small variations encountered are probably well within those of experimental error.

It will be observed that in the solution at pH 6.48 the calcium optimum for growth was about 100 mg. per liter and that residual acidity of the solution increased with calcium content. The increase in acidity persisted even with decreasing yields. At an acidity level of pH 5.98 the growth curve was much flatter because of the slightly increased yields at deficiency levels of 25 and 50 mg. of calcium per liter. A contributing factor was a moderate decrease in maximum yield. Acidities at harvest also increased at this initial pH, but less than at pH 6.48.

INFLUENCE OF ACIDITY ON MAGNESIUM REQUIREMENT

The relation of magnesium requirements to acidity of the nutrient solution is shown in figure 3. Determinations were made at three levels of initial acidity—pH 5.96, 5.31, and 4.34. The number of repetitions and the method of averaging values were the same as those in the calcium series. At pH 5.96 the maximum yield was obtained with 6 mg. of magnesium per liter. Increasing acidity decreased maximum yields only slightly and did not alter the optimum magnesium concentration. Increasing acidities also caused slight decreases in yield with suboptimum concentrations of magnesium. At harvest acidities were in all cases approximately the same and were influenced but little by the initial acidity of the nutrient solution.

DISCUSSION

Adjustments in hydrogen-ion concentration and magnesium or calcium content of the nutrient solution are of course not feasible without alterations in other constituents. Moreover, it seemed advisable in these experiments under aseptic conditions to follow the usual procedure of using sodium and chloride ions, that is, sodium nitrate, hydrochloric acid, and the chlorides of magnesium and calcium. The basis for this procedure is the apparent nonessentiality of sodium and chlorine for growth of green plants. Nevertheless, sodium and chloride ions cannot be assumed a priori to be without influence on growth. Similar series employing fluctuations in essential ions might also be

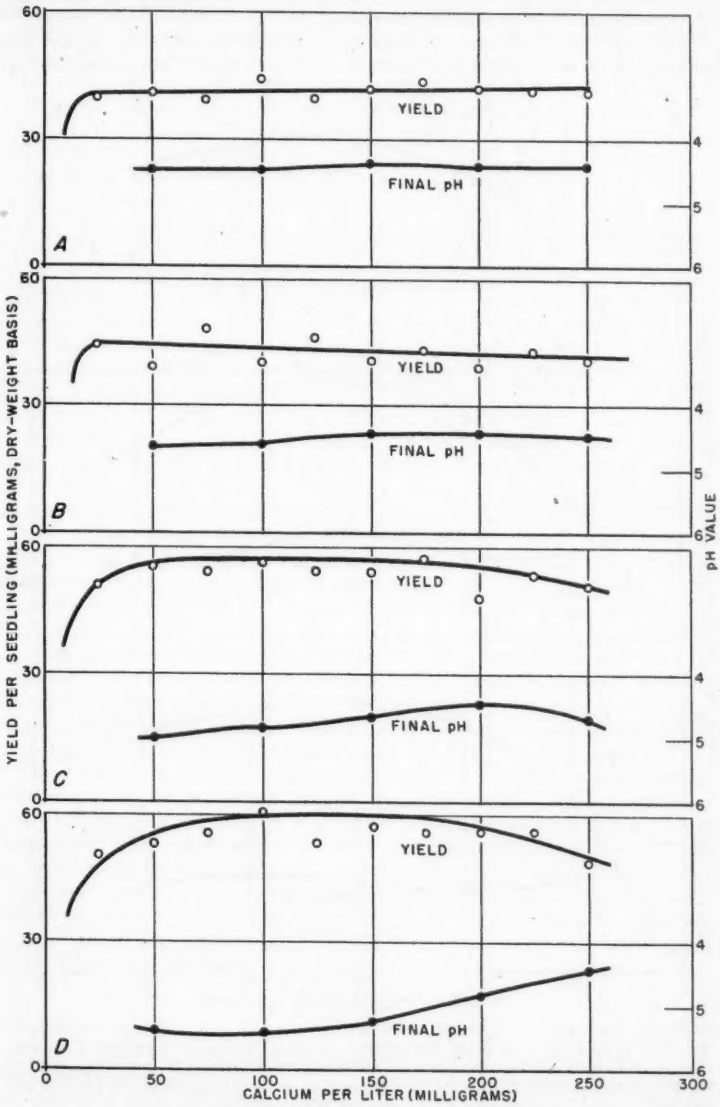

FIGURE 2.—Average acidities of solutions at harvest and average weights of Xanthi Turkish tobacco seedlings grown for 28 days with continuous illumination of 500 foot-candles in nutrient solutions containing different amounts of calcium and having different initial acidity levels: *A*, pH 4.39; *B*, pH 5.42; *C*, pH 5.98; and *D*, pH 6.48.

desirable for comparison, though it would be necessary to use initial excesses in order to avoid deficiencies.

The degree of influence of sodium and chloride ions in the calcium and magnesium series is indicated in several ways by the experimental

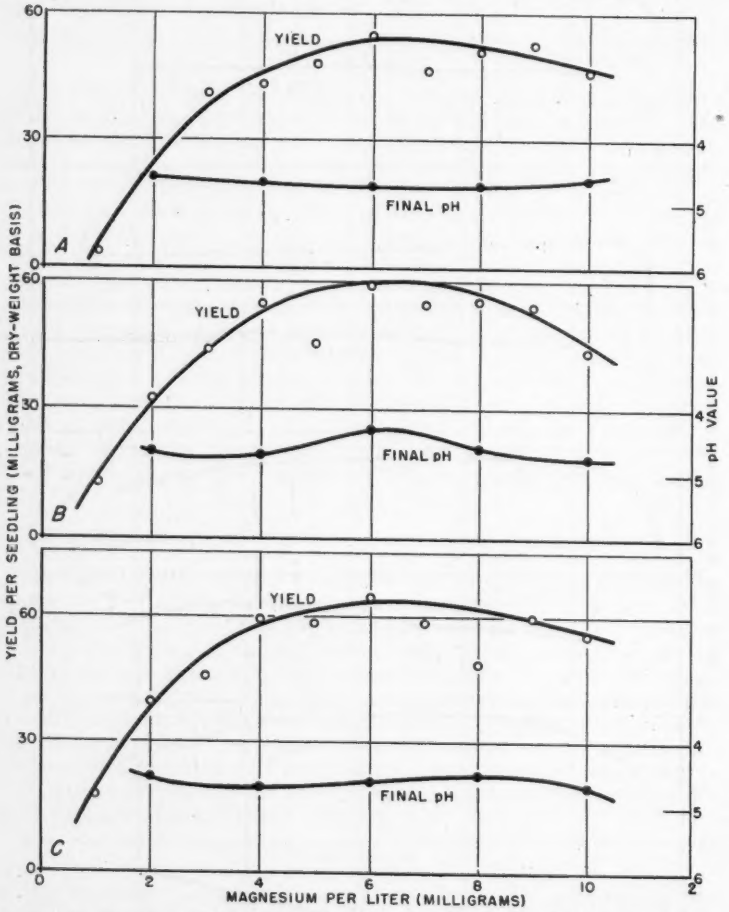

FIGURE 3.—Average acidities of solutions at harvest and average weights of Xanthi Turkish tobacco seedlings grown for 28 days with continuous illumination of 500 foot-candles in nutrient solutions containing different amounts of magnesium and having different initial acidity levels: *A*, pH 4.34; *B*, pH 5.31; *C*, pH 5.96.

data. The maximum yields in the two series were 63 mg. for magnesium and 60 mg. for calcium at the highest initial pH employed. The effects of a fivefold increase in sodium ion and of a sixfold increase in chloride ion as between the series are therefore rather small. Moreover, though the highest concentrations of chloride are concomitant

with those of magnesium and calcium, the depressions in yield at high nutrient levels were greatest in the magnesium series containing only one-fifth the chloride content. Furthermore, no symptoms of injury attributable to sodium or chlorine could be detected in either series.

The effects of increasing acidities on requirements of Xanthi Turkish tobacco seedlings were not entirely uniform for calcium and magnesium. With magnesium maximum yield decreased with increasing acidities within an initial range of pH 5.96 to 4.34. Since the optimum concentration of magnesium for growth remained unaltered, the magnesium requirement was thereby increased slightly. Increasing acidity also decreased maximum yield with calcium concentrations and so also increased the calcium requirement for growth. Increased acidity, however, increased yields at suboptimum concentrations of calcium and thus brought about a *relative* decrease in calcium requirements at intermediate acidity levels in the more acid series. At an initial acidity of pH 6.48, for example, yields with 25, 50, 75, and 100 mg. of calcium per liter were 49.6, 52.8, 56.4, and 61.2 mg., respectively; whereas the corresponding yields for an initial acidity of pH 5.98 were 51.3, 54.4, 54.5, and 56.3 mg. There was also a slight increase in absolute values for yields in the more acid series at suboptimum levels as compared with the less acid series. Furthermore, it should be noted that maximum yield was attained with 75 mg. of calcium with an initial pH of 5.98, whereas 100 mg. of calcium was required at pH 6.48.

These data cannot, however, be considered as proof that growth responses to calcium and magnesium display an intrinsic qualitative difference. The ranges used were not identical; that for magnesium extended from 0 to 166.67 percent of the optimum, whereas that for calcium was 0 to 250 percent of the optimum. Moreover, it is not certain but that the concentrations of other macronutrients and of the micronutrients used in the nutrient solution form the basis for these qualitative differences.

These data seem to indicate that acidity is not necessarily beneficial in a solution culture but that its action is dependent on the composition of the nutrient solution. Maximum yields were obtainable without resorting to an increased acidity to increase availability of nutrient ions. On the other hand, if a stock solution of much lower calcium content had been used, it is evident that increased acidity would have proved beneficial in the calcium series and perhaps also in the magnesium series. These statements might be summarized by stating that acidity may prove harmful to growth if all nutrient ions are present in ample quantity, but beneficial if there is a deficiency of calcium and perhaps of other elements.

SUMMARY

Xanthi Turkish tobacco seedlings were grown aseptically on 50 cc. of a mineral-salt solution in 200-cc. Erlenmeyer flasks at 25° C. with 500 foot-candles of white fluorescent illumination. The calcium and magnesium optima for growth were determined at several levels of initial acidity within the range pH 4 to 7 (adjusted with hydrochloric acid). Increased acidity brought about increased calcium and magnesium (as chlorides) requirements by decreasing growth with identi-

cal supply of these elements. Growth decreases were greater with increased acidity in the calcium series than in the magnesium series. Moreover, although the concentration-yield curves for magnesium remained practically unaltered in form with varying acidity, the analogous calcium curves tended to become straight. That is, the optimum for magnesium remained unaltered whereas that for calcium decreased with acidity. The residual solutions at harvest were usually slightly more acid than the unused nutrient solutions and were rather uniform in acidity under varying conditions.

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